PDHonline Course M475 (6 PDH)

Industrial Process Equipment – Testing, Inspection & Commissioning

Instructor: Jurandir Primo, PE

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PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

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Introduction:

Project commissioning is the process of assuring that all systems and components of a building or industrial plant are very well designed, installed, tested, operated, and maintained according to the operational requirements of the owner or final client. A commissioning process may be applied, not only to new projects, but also to existing units and systems subject to expansion, renovation or re-vamping.

In practice, the commissioning process comprises the integrated application of a set of engineering techniques and procedures to **check, inspect and test** every operational component of the project, from individual functions, such as instruments and equipment, up to complex installations, such as modules, subsystems and systems.

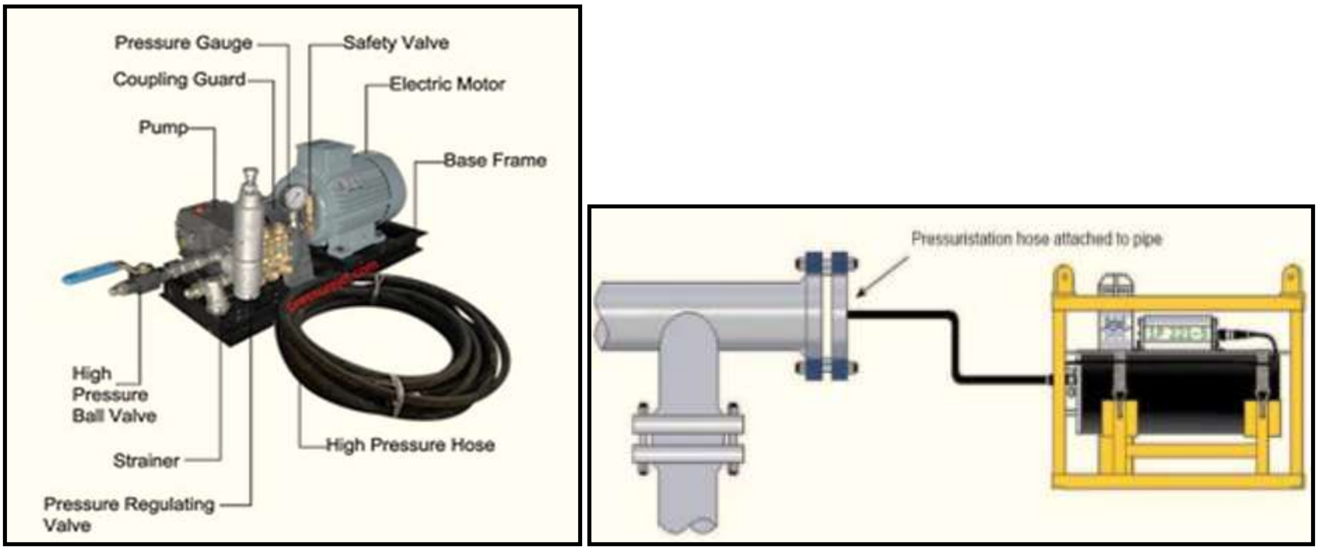
Commissioning activities, in the broader sense, are applicable to all phases of the project, from the basic and detailed design, procurement, construction and assembly, until the final handover of the unit to the owner, including sometimes an assisted operation phase.

Contents:

I. HYDROSTATIC TESTING:

A hydrostatic pressure test is a way in which **atmospheric tanks, pressure vessels, pipelines, gas cylinders, boilers and valves** are tested for **strength and leaks** through the weld or bolting and can be inspected and repaired. The **ASME VIII Div. 1, UG-99** - Standard Hydrostatic Testing defines the conditions to carry on the procedures.

As per ASME Section VIII-1, UG-99, the reviewed Hydrostatic Test Pressure Gage shall be equal **at least one 1.3 times the Maximum Allowable Working Pressure** (MAWP), **multiplied** by the ratio of the stress value **"S"** (materials of which the vessel is constructed) at the **Design Temperature** for the materials of which the pressure vessel is constructed.



Hydrostatic Testing Assembly

A hydrostatic test based on a calculated pressure may be used by **agreement between the user and the manufacturer**. For the basis for calculating test pressures, see **UA–60(e)** of the **ASME Code**. The descriptive **paragraphs** according to **ASME B31.3** for Hydrostatic Test Pressure are:

- **Hydrostatic Leak Testing:**

Paragraph 345.4.1 Test Fluid: The **fluid shall be water** unless there is the possibility of damage due to freezing or to adverse effects of water on the piping or the process. In this case another **suitable nontoxic liquid** may be used. If the liquid is flammable, its flash point shall be at least **49°C (120°F)**, and consideration shall be given to the test environment.

Paragraph 345.4.2 PressureTest: The hydrostatic test pressure at any point in a metallic piping system shall be as follows:

(a) Not less than **1.3 times** the design pressure;
(b) For design temperature **above the test temperature**, the minimum test pressure shall be calculated by the same equation as indicated below, except that the value of ***ST /S* shall not exceed 6.5**:

$$P_T = \frac{1.3.P.S_T}{S_D}$$

Where:

P_T = Minimum hydrostatic pressure test gauge;
P = Internal design gage pressure (MAWP);
S_T = Stress value of material at test temperature;
S_D = Stress value of material at design temperature (See Table A-1- ASME B31.3 Material Stresses).

If the test pressure as above would produce a nominal pressure stress or longitudinal stress in **excess of the yield strength** at test temperature, **the pressure test may be reduced to the maximum pressure that will not exceed the yield strength at test temperature**. The stress resulting from the hydrostatic test **shall not exceed 90%** of the **yield stress** of the material at the test temperature.

The **hydrostatic pressure test** shall be applied for a **sufficient period of time** to permit a thorough examination of all joints and connections. The test shall not be conducted until the vessel and liquid are at approximately the same temperature.

Defects detected during the Hydrostatic Testing or subsequent examination are completely removed and then inspected. The vessels requiring **Stress Relieving** after any welding repairs **shall be stress relieved** conforms to **UW–40 of the ASME Code**.

After **welding repairs** have been made, the vessel should be **hydro tested again** in the regular way, and if it passes the test, the Inspector and the Quality Engineer may accept it. If it does not pass the test they can order supplementary repairs, or, if the vessel is not suitable for service, they may permanently reject it.

The **fluid for the hydrostatic testing shall be water**, unless there is a possibility of damage due to freezing or to adverse effects of water on the piping or the process. In that case, another suitable non-toxic liquid may be used. So **glycol/water** is allowed.

II. PNEUMATIC TESTING:

Pneumatic testing for valves, pipelines and **welded pressure vessels shall be permitted** only for those specially designed that cannot be **safely filled with water**, or for those which **cannot be dried** to be used in services where **traces of the testing content** cannot be tolerated.

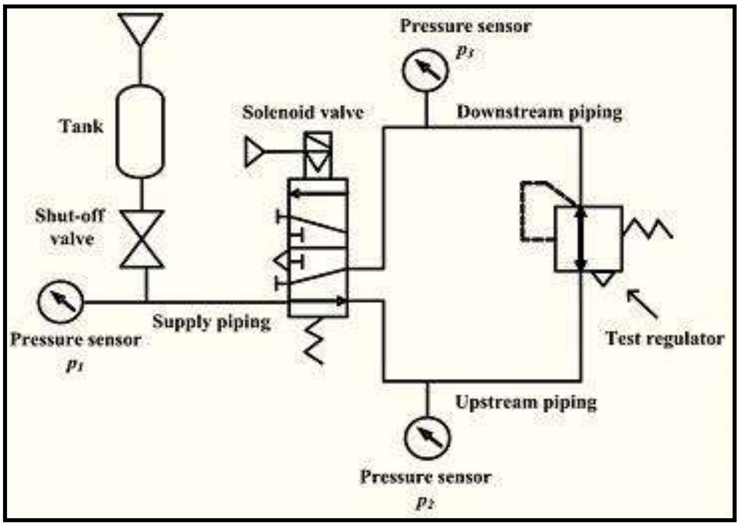
There are two types of procedures for pneumatic testing, as shown below:

1) The **pneumatic pressure test** shall be at least equal to **1.25 times the Maximum Allowable Working Pressure (MAWP) multiplied** by the ratio of the stress value **''S''** at the **test temperature.** The **Design Temperature** is for materials which the equipment is constructed (see **UG–21** of ASME).

$$P_T = \frac{1.25 . P . S_T}{S_D}$$

Where:

P_T = Minimum pneumatic pressure test gauge
P = Internal design gage pressure (MAWP)
S_T = Stress value of material at test temperature
S_D = Stress value of material at design temperature (See Table A-1- ASME B31.3 Material Stresses).



Pneumatic Test Sketch

2) According to **UG-100**, the pneumatic test shall be at least **equal to 1.1 times the MAWP multiplied** by the lowest ratio for the materials of the stress value **"S"**, at the **test temperature**. The **Design Temperature** may be used in lieu of the **standard hydrostatic test** prescribed in **UG-99** for vessels under certain conditions:

- For vessels that **cannot safely be filled** with water;
- For vessels that **cannot be dried** and to be used in a service where **traces of the testing content** cannot be tolerated and previously tested by hydrostatic pressure as required in **UG-99**.

Then, the formula becomes:

$$P_T = \frac{1.1.P.S_T}{S_D}$$

As a **general** method, the pneumatic test pressure is **1.25 MAWP** for materials ASME Section VIII - **Division 1** and **1.1 MAWP** for materials ASME Section VIII - **Division 2**. The pneumatic test procedure for pressure vessels **should be accomplished** as follows:

The pressure on the vessel **shall be gradually increased** to not more than **half the test pressure**. After, the pressure will then be **increased at steps** of approximately **1/10 the test pressures** until the test pressure has been reached. In order to permit examination, **the pressure** will then **be reduced** to the **Maximum Allowable Working Pressure** of the vessel.

The tank supports and saddles, connecting piping, and insulation if provided shall be examined to determine if they are satisfactory and that no leaks are evident. The pneumatic test is inherently **very dangerous and more hazardous than a hydrostatic test**, and **suitable precautions** shall be taken to protect personnel and adjacent property.

III. PRESSURE TESTS FOR VALVES:

The **API 598, API 6D, IS0 14313** and other standards covers inspection, examination, supplementary examinations and pressure test requirements for resilient-seated, nonmetallic-seated (e.g., ceramic) and metal-to-metal-seated valves of the gate, globe, plug, ball, check, and butterfly types.

- **Shell Test (Hydrostatic Body Test):**

Every valve shall be subjected to a **hydrostatic test** of the body shell at **1.5 times** the maximum permissible working pressure at 100 °F (38 °C). The test shall show no leakage, no wetting of the external surfaces, and no permanent distortion under the full test pressure, as specified in **Table 1**.

The valve shall be set in the partially open position for this test, and completely filled with the test fluid. Any entrapped air should be vented from both ends and the body cavity. The valve shall then be brought to the required test pressure. All external surfaces should be dried and the pressure held for at least the minimum test duration.

There shall be no visible leakage during the test duration. The **stem seals** should be capable of retaining pressure at least 100 °F (38 °C) without leakage. If leakage is found, corrective action may be taken to eliminate the leakage and the test repeated, specified below and in **Table 2**.

a) **Backseat Stem Test: (Hydrostatic Seat Test):**

When applicable (with exception of bellows seal valves), every valve shall be subjected to a hydrostatic test of the **backseat stem** at **1.1 times** the maximum permissible working pressure at 100 °F (38 °C), done by opening the valve to the fullest, loosening the packing gland and pressurizing the shell. All external surfaces should be dried and the pressure held for at least the minimum test duration, as specified in **Table 1**.

If **unacceptable leakage** is found, corrective action may be taken to eliminate the leakage and the test repeated. If the valve is disassembled to eliminate the leakage, all previous testing must be repeated upon re-assembly. There shall be no visible leakage during the test duration specified in **Table 2**.

b) High-pressure Closure Test (Hydrostatic Seat Test):

Every valve shall be subjected to a **hydrostatic seat test** to **1.1 times** the maximum permissible working pressure at 100 °F (38 °C). The test shall show no leakage **through the disc**, behind the seat rings or past the shaft seals. The allowable leakage of test fluid for the seat seal, shall be according to those listed in **Table 3**.

If **unacceptable leakage** is found, corrective action may be taken to eliminate the leakage and the seat test repeated. If the valve is disassembled to eliminate the leakage, all previous testing must be repeated upon re-assembly.

c) Pneumatic Seat Test - Low-pressure Closure Test:

Every valve shall be subjected to an **air seat test** at a minimum pressure from **4 to 7 bar (60-100 psig)** according to test duration specified in **Table 2**. The test shall show no leakage through the disc, behind the seat rings or past the shaft seals. The allowable leakage of test fluid from the seat seal shall be according to those listed in **Table 3**.

Check for leakage using either a **soap film solution** or an **inverted 'U' tube** with its outlet submerged under water. If the seat pressure is held successfully then the other seat shall be tested in the same manner where applicable.

If **unacceptable leakage** is found, corrective action may be taken to eliminate the leakage and the seat test repeated. If the valve is disassembled to eliminate the leakage, all previous testing must be repeated upon re-assembly.

d) Fluid for Testing:

Hydrostatic tests shall be carried out with **water** at ambient temperatures, within the range of 41°F (5°C) and 122°F (50°C) and shall contain **water-soluble oil or rust inhibitors**. **Potable water** used for pressure test of **austenitic stainless steel** valves shall have a **chloride** content less than **30 ppm** and for **carbon steel** valves shall be **less** than **200 ppm**.

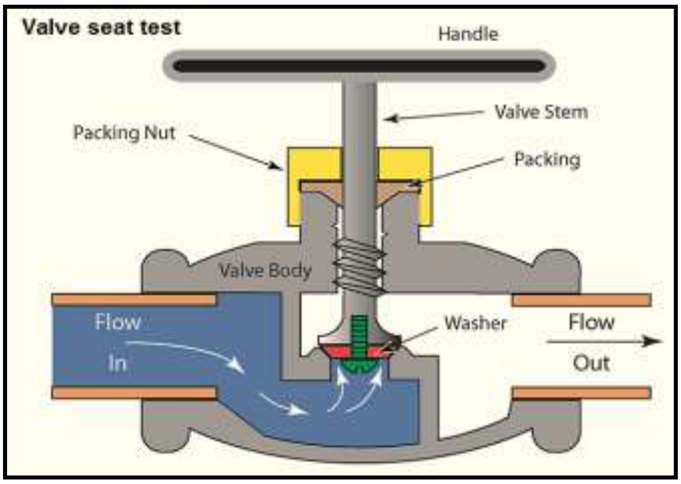


TABLE 1 – TEST PRESSURE (ASME B 16.34 & API Std. 602 for Class 800 Valves)

Class	150#			300#		
Description / Material	CWP	Shell	Seat	CWP	Shell	Seat
	psig	Kg/cm²	Kg/cm²	psig	Kg/cm²	Kg/cm²
A105, A350-LF2	285	32	23	740	80	59
A182-F5,F9,F11,F22	290	32	23	750	80	59
A182-F304,F316	275	30	23	720	78	57
A182-F304L, F316L	230	25	20	600	64	48
Class	**600#**			**800#**		
Description / Material	CWP	Shell	Seat	CWP	Shell	Seat
	psig	Kg/cm²	Kg/cm²	psig	Kg/cm²	Kg/cm²
A105, A350-LF2	1480	157	117	1975	210	153
A182-F5,F9,F11,F22	1500	159	117	2000	211	155
A182-F304,F316	1440	153	113	1920	204	150
A182-F304L, F316L	1200	127	94	1600	169	125

TABLE 2 – TEST DURATION

NOMINAL SIZE (NPS)	MINIMUM TEST DURATIONS (Seconds)			
	Hydro Shell Test	Backseat Test	Hydro Seat Test	Air Seat Test
≤ 2″	15	15	15	15
2 ½″ – 6″	60	60	60	60
8″ – 12″	120	60	120	120
≥ 14″	300	60	120	120

TABLE 3 – MAXIMUM ALLOWABLE LEAKAGE RATES

NOMINAL SIZE (NPS)	Gate & Globe Valves		Check Valves	
	Liquid Test[a] (Drops Per Minute)	Gas Test (Bubbles Per Minute)	Liquid Test	Gas Test
≤ 2″	0 [b]	0 [c]	3 scc x NPS / minute.	700 scc x NPS / minute
2 ½″ – 6″	12	24		
8″ – 12″	20	40		
≥ 14″	d	e		

- **a)** For the liquid test, 1 millilitre is considered equivalent to 16 drops;
- **b)** For the liquid test, 0 drops means no visible leakage per minimum duration of the test.
- **c)** For the gas test, 0 bubbles means less than 1 bubble per minimum duration of the test.
- **d)** For valves greater than or equal to 14” (NPS 14), the maximum permissible leakage rate shall be 2 drops per minute per inch NPS size.
- **e)** For valves greater than or equal to 14” (NPS 14), the maximum permissible leakage rate shall be 4 bubbles per minute per inch NPS size.

Soft-seated valves and **lubricated plug valves** shall not exceed leakage in **IS0 5208 Rate A**. For **metal-seated valves** the leakage rate shall not exceed (or not more than two times) the **IS0 5208 Rate D,** unless otherwise specified.

e) Test Certification:

All tests should be always specified by the Purchaser. The manufacturer should issue a **test certificate** according to **API 598** confirming that the valves have been tested **in accordance** with the requirements.

f) Valve Hydrostatic Test - ASME B16.34 Requirements:

Hydrostatic shell test at a pressure no less than **1.5 times** the **MAWP** at 100 °F, rounded off to next higher **25 psi increment**. The test made with **water** must contain a **corrosion inhibitor**, with kerosene or with other suitable fluid with a viscosity not greater than that of water, at a temperature not above 125 °F. Visually detectable leakage through pressure boundary walls shall not be acceptable.

Valve size inches	Test time (seconds)
2 and smaller	15
2.5 to 8	60
10 and larger	180

g) Valve Closure Tests:

Each valve designed for **shut-off or isolation service**, such as a stop valve and each valve designed for limiting flow reversal, such as a check valve, shall be given a **hydrostatic closure test**. The test pressure shall be not less than **110%** at 100 °F rating. Except that, a **pneumatic closure test** at a pressure not less than **80 psi** may be substituted for valve sizes and pressure classes shown below.

Valve Size	Pressure Class
≤ 4	All
≤ 12	≤ 400

Note: The **closure test shall follow the shell test** except for valves 4 in. and smaller up to Class 1500. The closure test **may precede the shell test**. When a **pneumatic closure test** is used, not less than duration shown below.

Valve size inches	Gas Test duration (Seconds)
≤ 2	15
2 1/2 to 8	30
10 to 18	60
≥ 20	120

h) Seat Leakage Classification:

There are actually **six different seat leakage** classifications as defined by **ANSI/FCI 70-2 2006** (European equivalent standard **IEC 60534-4**).

- **Class I:**

Identical to Class II, III, and IV in construction and design, but no shop test is made, also known as dust tight and can refer to metal or resilient seated valves.

- **Class II:**

For double port or balanced single port valves with a metal piston ring seal and metal to metal seats.

- 0.5% leakage of full open valve capacity.
- Service dP or 50 psid (3.4 bar differential), whichever is lower at 50 to 125 °F.
- Test medium air at 45 to 60 psig is the test fluid.

- **Class III:**

- 0.1% leakage of full open valve capacity.
- Service dP or 50 psid (*3.4 bar differential*), whichever is lower at 50 to 125 °F.
- Test medium air at 45 to 60 psig is the test fluid.
- For the same types of valves as in Class II.

Typical constructions:

- Balanced, double port, soft seats, low seat load
- Balanced, single port, single graphite piston ring, lapped metal seats, medium seat load

- **Class IV:**

- *0.01%* leakage of full open valve capacity.
- Service dP or *50 psid (3.4 bar differential)*, whichever is lower at *50 to 125 °F*.
- Test medium air at *45 to 60 psig* is the test fluid.

Typical constructions:

- Class IV is also known as metal to metal
- Balanced, single port, Teflon piston ring, lapped metal seats, medium seat load
- Balanced, single port, multiple graphite piston rings, lapped metal seats
- Unbalanced, single port, lapped metal seats, medium seat load

- **Class V:**

- Leakage is limited to *5 x 10 ml* per minute per inch of orifice diameter per psi differential.
- The test fluid is water at *100 psig* or operating pressure.
- Service dP at *50 to 125 °F*.
- For the same types of valves as Class IV.

Typical constructions:

- Unbalanced, single port, lapped metal seats, high seat load

- Balanced, single port, Teflon piston rings, soft seats, low seat load
- Unbalanced, single port, soft metal seats, high seat load

- **Class VI:**

Commonly known as a soft seat classification, where the seat or shut-off disc or both are made from some material such as Teflon. Intended for resilient seating valves.

- The test fluid is **air or nitrogen**.
- Pressure is the **lesser of *50 psig*** or operating pressure.
- Leakage depends on valve size, from 0.15 to 6.75 ml per minute, sizes from *1* to *8 inches*.

i) Most Common Leakage Tests:

The most common used tests are:

- **CLASS IV:** is also known as metal to metal. Leakage rate with a **metal plug** and **metal seat**.

- **CLASS VI:** is known as soft seat. Plug or seat made from material such as **Teflon** or similar.

j) Table for Valve Leakage Classification and Test Procedures:

Leakage Class Designation	Maximum Leakage Allowable	Test Medium	Test Pressure	Testing Procedures Rating
I	x	x	x	No test required
II	0.5% of rated capacity	Air or water at 50 - 125^{o} F (10 - 52^{o}C)	45 - 60 psig or maximum operating differential whichever is lower	45 - 60 psig or maximum operating differential whichever is lower
III	0.1% of rated capacity	As above	As above	As above
IV	0.01% of rated capacity	As above	As above	As above
V	0.0005 ml per minute of water per inch of port diameter per psi differential	Water at 50 to125^{o}F (10 to 52^{o}C)	Maximum service pressure drop across valve plug not to exceed ANSI body rating	Maximum service pressure drop across valve plug not to exceed ANSI body rating
VI	Not to exceed amounts shown in the table above	Air or nitrogen at 50 to 125^{o} F (10 to 52^{o}C)	50 psig or max rated differential pressure across valve plug whichever is lower	Actuator should be adjusted to operating conditions specified with full normal closing thrust applied to valve plug seat

k) Valve Bubble Shut-Off Test Procedure:

Port Diameter		Bubbles per minute	ml per minute
Inches	Millimeters		
1	25	1	0.15
1 1/2	38	2	0.30
2	51	3	0.45
2 1/2	64	4	0.60
3	76	6	0.90
4	102	11	1.70
6	152	27	4.00
8	203	45	6.75
10	254	63	9
12	305	81	11.5

- **Gate Valve & Screw Down Non-Return Globe Valve**: The pressure shall be applied successively to **each side** of the closed valve with the other side open to the atmosphere to check for leakage at the atmospheric side of the closure.

- **Globe Valve**: The pressure shall be applied **in one direction** with the pressure applied under the disc (upstream side) of the closed valve with the other side open to the atmosphere to check for leakage at the atmospheric side of the closure.

- **Check Valve**: The pressure shall be applied **in one direction** with the pressure applied behind the disc (downstream side) of the closed valve with the other side open to the atmosphere to check for leakage at the atmospheric side of the closure.

l) Valve Flow Coefficients:

The **Flow Coefficient Cv (or Kv)**, literally means "coefficient of velocity" used to compare flows of valves. The higher the Cv, the greater the flow. When the valve is opened, most of the time, a valve should be selected with low head loss in order to save energy. Use the following equations:

- Volumetric flow rate units:

$$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

- Mass flow rate units:

$$C_v = \frac{w}{N_6 F_p \sqrt{(P_1 - P_2)\gamma}}$$

- Other formulas considering Cv are:

$$Q = Cv \times \sqrt{\frac{\Delta P \times 62.4}{\rho}}$$

$$Q = Kv \times \sqrt{\frac{\Delta P \times 1000}{\rho}}$$

Where:

Q = Flow rate in gallons per minute (GPM);
ΔP = Pressure drop across the valve psi - (62.4 = fluid conversion factor);
ρ = Density of fluids in lb/ft³ - (according to temperature).

Obs.:

Kv is the Flow Coefficient in metric units. It is defined as the flow rate in **cubic meters per hour [m³/h]** of water at a temperature of **16 ºC** with a pressure drop across the valve of **1 bar.**

Cv is the Flow Coefficient in imperial units. It is defined as the flow rate in **US gallons per minute [gpm]** of water at a temperature of **60 ºF** with a pressure drop across the valve of **1 psi**.

Kv = 0.865·Cv
Cv = 1,156·Kv

Flow Coefficient Table. Select the valve size using the appropriate manufacturer's and the calculated **Cv value**, considering 100% travel:

Representative Sizing Coefficients for Single-Ported Globe Style Valve Bodies

Valve Size (inches)	Valve Plug Style	Flow Characteristic	Port Dia. (in.)	Rated Travel (in.)	C_V	F_L	X_T	F_D
1/2	Post Guided	Equal Percentage	0.38	0.50	2.41	0.90	0.54	0.61
3/4	Post Guided	Equal Percentage	0.56	0.50	5.92	0.84	0.61	0.61
1	Micro Form™	Equal Percentage	3/8	3/4	3.07	0.89	0.66	0.72
			1/2	3/4	4.91	0.93	0.80	0.67
			3/4	3/4	8.84	0.97	0.92	0.62
	Cage Guided	Linear	1 5/16	3/4	20.6	0.84	0.64	0.34
		Equal Percentage	1 5/16	3/4	17.2	0.88	0.67	0.38
1 1/2	Micro-Form™	Equal Percentage	3/8	3/4	3.20	0.84	0.65	0.72
			1/2	3/4	5.18	0.91	0.71	0.67
			3/4	3/4	10.2	0.92	0.80	0.62
	Cage Guided	Linear	1 7/8	3/4	39.2	0.82	0.66	0.34
		Equal Percentage	1 7/8	3/4	35.8	0.84	0.68	0.38
2	Cage Guided	Linear	2 5/16	1 1/8	72.9	0.77	0.64	0.33
		Equal Percentage	2 5/16	1 1/8	59.7	0.85	0.69	0.31
3	Cage Guided	Linear	3 7/16	1 1/2	148	0.82	0.62	0.30
		Equal Percentage			136	0.82	0.68	0.32
4	Cage Guided	Linear	4 3/8	2	236	0.82	0.69	0.28
		Equal Percentage			224	0.82	0.72	0.28
6	Cage Guided	Linear	7	2	433	0.84	0.74	0.28
		Equal Percentage			394	0.85	0.78	0.26
8	Cage Guided	Linear	8	3	846	0.87	0.81	0.31
		Equal Percentage			818	0.86	0.81	0.26

Obs.: See, as shown below, other Flow Coefficients may indicate different numbers, at 100% travel:

GATE VALVE Cv's

CLASS 150													
SIZE	2"	2-1/2"	3"	4"	6"	8"	10"	12"	14"	16"	18"	20"	24"
Cv	298	466	694	1,234	2,873	5,109	8,622	12,416	17,651	23,055	30,603	37,782	57,349
CLASS 300													
SIZE	2"	2-1/2"	3"	4"	6"	8"	10"	12"					
Cv	289	452	672	1,194	2,776	4,935	7,982	11,929					

GLOBE VALVE Cv's

CLASS 150								
SIZE	2"	2-1/2"	3"	4"	6"	8"	10"	12"
Cv	46	72	105	166	400	810	1,310	1,900
CLASS 300								
SIZE	2"	2-1/2"	3"	4"	6"	8"	10"	
Cv	46	84	104	165	436	692	1,120	

SWING CHECK VALVE Cv's

CLASS 150												
SIZE	2"	2-1/2"	3"	4"	6"	8"	10"	12"	14"	16"	18"	20"
Cv	218		499	903	2,032	3,679	5,857	8,435	11,708	15,293	19,754	24,912
CLASS 300												
SIZE	2"	2-1/2"	3"	4"	6"	8"	10"	12"				
Cv	211	330	482	858	1,963	3,549	5,546	8,128				

IV. LEAK TESTING - FLUIDS AND PROCEDURES:

The **choice of liquid or gas** depends on the test purpose and the leakage that can be tolerated. Leaking **air or gas** can be detected by the sound of the escaping gas, by use of a **soap film that forms bubbles**, or by immersion in a liquid in which the escaping gas forms bubbles.

For hydrostatic or gas tests, a pressure gage attached, indicates leaks by the drop in pressure after the tests begin. Dyes introduced in liquids and tracers introduced into gases can also indicate leakage. Weld **defects that cause leakage** are not always detected by the usual NDT methods.

A tight **crack or fissure** may not appear on a **radiograph**, yet will form a leak path. A production operation, such as forming or a proof test, may make leaks develop in an otherwise acceptable weld joint. A leak test is usually done after the vessel is completed and all the weld joints can be inspected, there will be no more fabricating operations and the inspection should be taken with the empty vessel.

The most common types of leak testings are described below:

1. The pressure-rise test method, is a vessel attached to a vacuum pump evacuating to a pressure of 0.5 psi absolute. The connections to the vacuum pump are sealed off and the internal pressure of the part is measured.

The **pressure** is measured again **after 5 minutes**. If the pressure in the evacuated space remains constant, the welds are free of leaks. If there is a pressure rise, at least one leak is present, then the helium-leak test below must be used.

2. The helium-leak test, is more precise than the pressure-rise method and is used to find the exact location of these leaks. Helium-leak testing is not used to inspect large items. This inspection method requires the use of a helium mass spectrometer to detect the presence of helium gas.

The **mass spectrometer** is connected to the **pumping system** between the vacuum pump and the vessel being inspected. Then the vessel is evacuated by a vacuum pump to a pressure of less than 50 microns of mercury. The mass spectrometer can detect helium directed at the atmosphere.

If there is a **small jet of helium gas** is aside the weld joint exposed, **there is a leak**. Some of the helium is sucked through the evacuated space and the mass spectrometer immediately indicates the presence of helium.

When **no leak** is present, no indication of gas helium will appear on the mass spectrometer. The exact location of leaks, shows the jet of helium on the surface of the weld joint. If there is an indication of leak, it is at the point where the helium jet is hitting the surface of the weld joint.

3. Ultrasonic translator detector, uses the ultrasonic sounds of **gas molecules escaping** from a vessel under pressure or vacuum. The sound created is in the frequency range of **35,000 and 45,000 Hz**, which is above the range of human hearing is, therefore, classified as ultrasonic. The short wave length of the frequencies permits the use of highly directional microphones.

Any piping or vessel **pressurized or evacuated to a pressure of 3 psi** can be inspected. The operator simply listens to the translated ultrasonic sounds while **moving a hand-held probe** along the weld (as a flashlight). The detectors are simple and require minimum operator training.

4. The air-soap solution test, can be conducted on a vessel **during or after** assembly. The vessel is subjected to an internal gas pressure not exceeding the design pressure. A soap or equivalent solution is applied so that connections and welded joints can be examined for leaks.

5. Air-ammonia test, involves **introducing air** into the vessel until a percent of the design pressure is needed. Anhydrous ammonia is then introduced into the vessel until **55%** of the design pressure is reached. Air is then reintroduced until the design pressure is reached.

Each joint is carefully examined by **using a probe or a swab wetted** with 10N solution of muriatic acid (HCL), a sulphur candle, or sulphur dioxide. A **wisp** of white smoke indicates a leak.

6. Hydrostatic tests, use **distilled or demineralized water** having a **pH of 6 to 8** and an impurity content not greater than **5 ppm** is used. Traces of water should be removed from the inside before the final leak testing is begun.

7. Water submersion test, the vessel is completely **submerged in clean water**. The interior is pressurized with gas, but the design pressure must not be exceeded. The size and number of **gas bubbles** indicate the size of leaks.

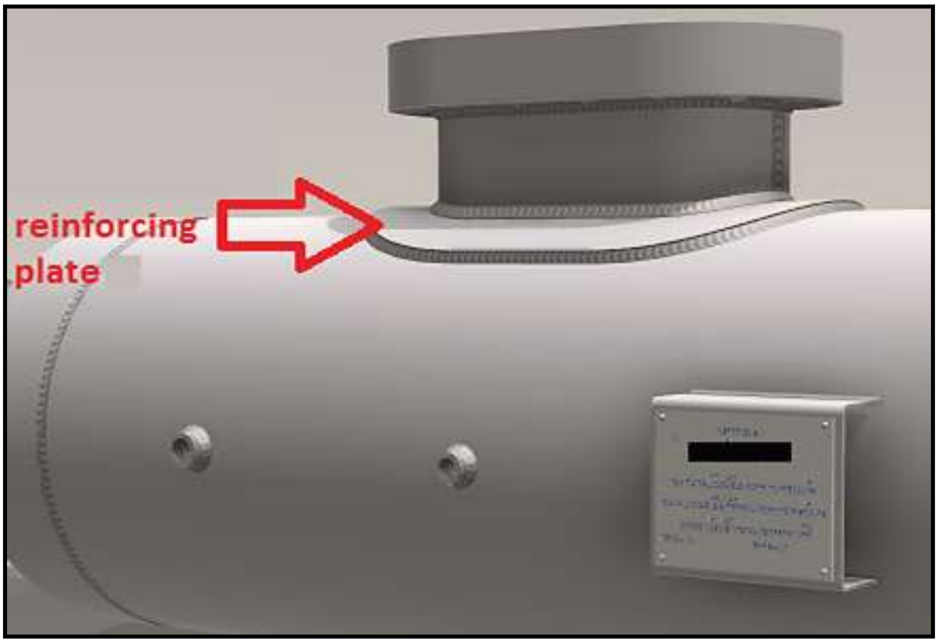
8. Halide torch test, the vessel is pressurized with a mixture of **50% Freon** and **carbon dioxide** or **50% Freon** and **nitrogen** is used. Each joint is carefully **probed** with a **halide torch** to detect leaks, which are indicated by a change in the color of the flame.

9. Halogen snifter test, use a **Freon inert gas mixture** introduced into the vessel until the design pressure. About **1 ounce** of Freon for every **30 ft^3** of vessel volume is required. The Inspector passes the **probe** of a **halogen vapor analyzer** over the area to be explored.

This probe is held about 1/2 inch from the surface being tested and is moved at about 1/2 inch per second. Since the instrument responds even to cigarette smoke and vapor from newly dry-cleaned clothing, the air should be kept substantially clean.

V. LEAK TESTING - WELDED REINFORCING PLATES:

This test aims to detect defects in welds, for **welded reinforcing plates**; overlapping joints fillet welds of storage tanks and connection bottom-sides, fillet welded. It is also used for the detection of defects in plates and castings. There are **two methods**: positive and negative pressure.



1) The **positive pressure** is based on application of a **bubble forming solution**, with each piece inspected of at least **0.7 (10 psi) to 1.0 kg/cm^2 (14.5 psi)**, forcing the passage of air and forming bubbles outside the welded reinforcing plate.

2) The **negative pressure** is the angle welds testing in overlapping joints (bottom of tanks) and gaskets between the sides and bottom of a tank with formation of vacuum of at least **0.15 kgf/cm^2 (2 psi)** beneath the absolute pressure. This pressure is obtained through a vacuum box.

The most common test that aims to guarantee the tightness of a system, by locating defects in welded plates or reinforcing plates is the positive pressure test.

Application examples:

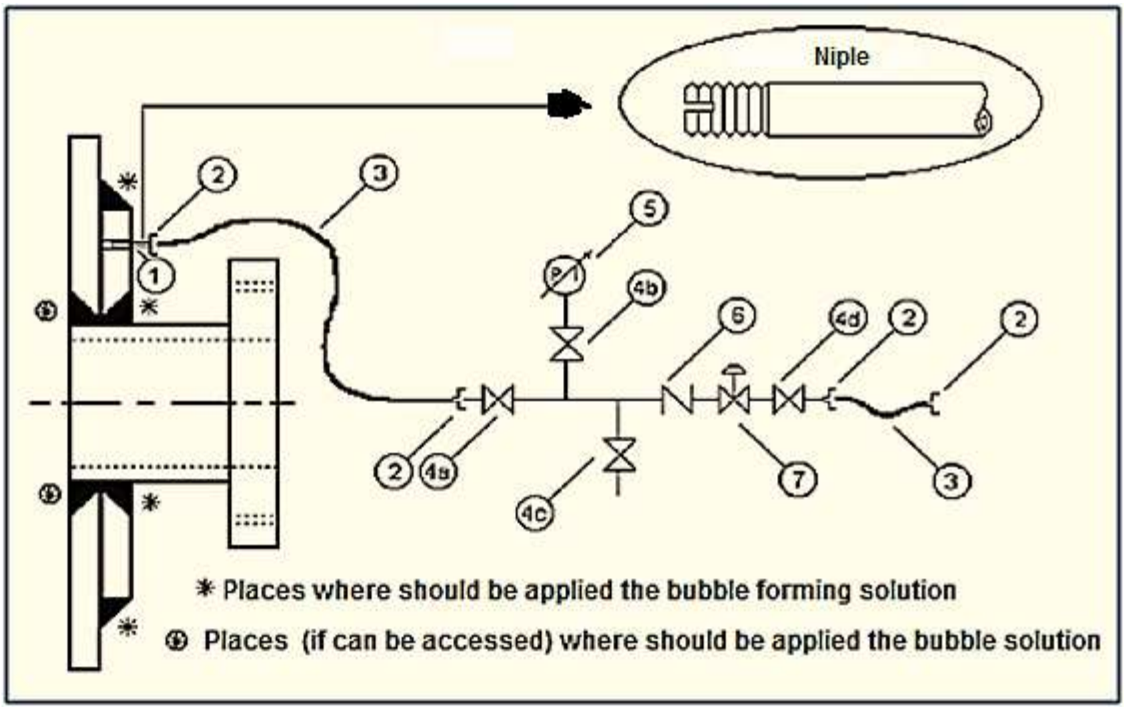
- ✓ Welds of reinforcing plates;
- ✓ Fillet welds of overlapped joints in deep tanks;
- ✓ Bottom-side connection weld on tanks.

The test methods are:

1) Formation of bubbles with **Positive Pressure**

- Weld test of connection reinforcement plates
- Testing of welds of metallic coatings

- Weld test of connection reinforcement plates
- Testing of welds of metallic coatings
- Pressure must not exceed the maximum value established
- Excessive pressure can cause blistering of the reinforcing plate
- Pressure usually **0.7 (10 psi) to 1.0 kg/cm^2 (14.5 psi)**

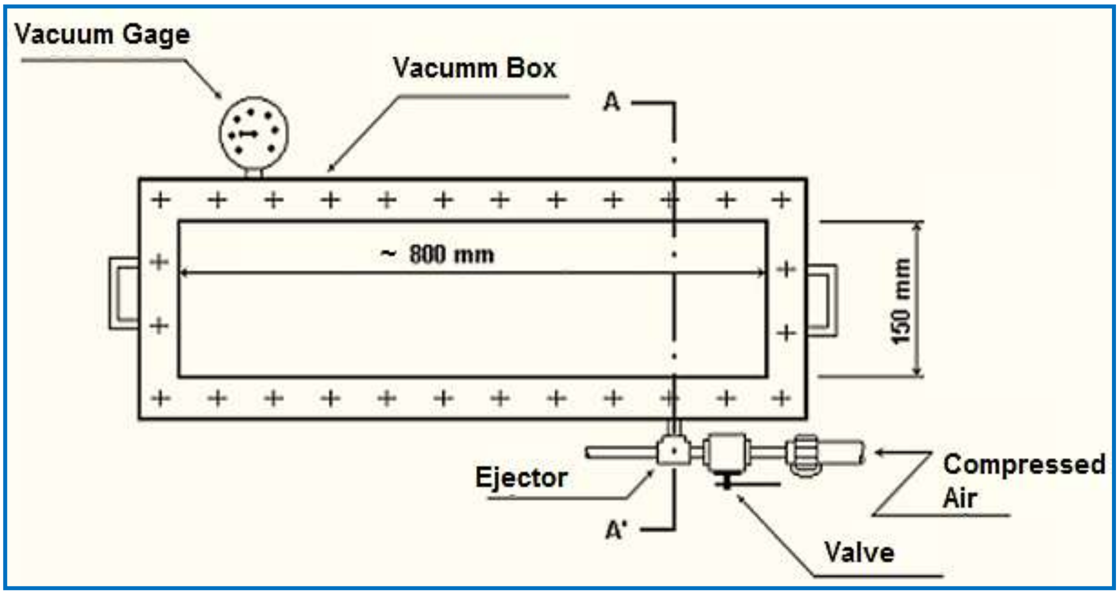


Test sequence:

- ✓ Cleaning of the joints
- ✓ Seal
- ✓ Pressurization
- ✓ Pressurization time - minimum **15 minutes**
- ✓ Test liquid application
- ✓ Inspection
- ✓ Cleaning
- ✓ Report

2) Formation of bubbles with **Negative Pressure:**

- Angle welds essay in overlapping joints (bottom of tanks);
- Angle welds testing in the gasket between the sides and bottom of the tank;
- Formation of vacuum of at least **0.15 kgf/cm^2 (2 psi)** beneath the absolute pressure;
- Pressure obtained through a vacuum box.



Test sequence:

- ✓ Cleaning of the joints
- ✓ Test liquid application
- ✓ Application of negative pressure
- ✓ Pressurization time - usually **10 seconds**
- ✓ Inspection
- ✓ Cleaning
- ✓ Report

Capillarity:

- ✓ Net application with large capillary effect;
- ✓ After some time of penetration, inspect the opposite by looking for traces of the liquid used;
- ✓ Liquid with difficult evaporation (diesel oil, kerosene, liquid penetrant test)

  - **Essay by**:
    - Angle welds on the board between the sides and bottom of the tank;
    - Angle welds in floating ceiling compartment;
    - Angle welds essay in overlapping joints (bottom of tanks);
    - Angle welds testing in the gasket between sides and bottom of the tank.

VI. THE DECIBEL:

The decibel (dB) is **one tenth** of a **Bel,** which is a unit of measure that was developed by engineers at Bell Telephone Laboratories and named for **Alexander Graham Bell**. The **dB** is a logarithmic unit that describes a ratio of two measurements. The basic equation that describes the difference in decibels between two measurements is:

$$\boxed{\Delta X(dB) = 10\log\frac{X_2}{X_1}}$$

Where:

Δ X = is the difference in some quantity expressed in decibels;
X_1 and X_2 = are two different measured values of X, and the log is to base 10.

a) Use of the dB in Sound Measurements:

The equation used to describe the difference in intensity between two ultrasonic or other sound measurements is:

$$\boxed{\Delta I(dB) = 20\log\frac{P_2}{P_1}}$$

Where:

ΔI = difference in sound intensity expressed in decibels (dB);
P_1 and P_2 = two different sound pressure measurements, log base 10.

Note: The factor of two difference between this basic equation for the dB and the one used when making sound measurements. This difference will be explained in the next section.

Sound intensity is defined as the sound power per unit area perpendicular to the wave. Units are typically in watts/m^2 or watts/cm^2. For sound intensity, the dB equation becomes:

$$\boxed{\Delta I(db) = 10\log\frac{I_2}{I_1}}$$

However, the power or intensity of sound is generally not measured directly. Since sound consists of pressure waves, one of the easiest ways to quantify sound is to measure variations in pressure (i.e. the **amplitude of the pressure wave**). When making ultrasound measurements, a transducer is used, which is basically a small microphone.

Transducers like most other microphones can produce a voltage that is approximately proportionally to the **sound pressure** (P). The power carried by a traveling wave is proportional to the square of the amplitude. Therefore, the equation used to quantify a difference in sound intensity based on a measured difference in sound pressure becomes:

$$\Delta I(db) = 10\log\frac{I_2}{I_1} = 10\log\frac{P_2^2}{P_1^2} = 20\log\frac{P_2}{P_1}$$

The factor of 2 is added to the equation because the logarithm of the square of a quantity is equal to 2 times the logarithm of the quantity. Since transducers and microphones produce a voltage that is proportional to the sound pressure, the equation could also be written as:

$$\Delta I(db) = 20\log\frac{V_2}{V_1}$$

Where:

ΔI = change in sound intensity incident on the transducer,
V_1 and V_2 = are two different transducer output voltages.

b) Use of dB units:

Use of dB units allows ratios of various sizes to be described using easy to work with numbers. For example, consider the information in the table, to **dB = 10 log**.

Ratio between Measurement 1 and 2	Equation	dB
1/2	dB = 10 log (1/2)	-3 dB
1	dB = 10 log (1)	0 dB
2	dB = 10 log (2)	3 dB
10	dB = 10 log (10)	10 dB
100	dB = 10 log (100)	20 dB
1,000	dB = 10 log (1000)	30 dB
10,000	dB = 10 log (10000)	40 dB
100,000	dB = 10 log (100000)	50 dB
1,000,000	dB = 10 log (1000000)	60 dB
10,000,000	dB = 10 log (10000000)	70 dB
100,000,000	dB = 10 log (100000000)	80 dB
1,000,000,000	dB = 10 log (1000000000)	90 dB

From this **table** it can be seen that **ratios from one up to ten billion** can be represented with a single or double digit number. The focus of this discussion is on using the **dB** in **measuring sound levels**, but it is also widely used when measuring power, pressure, voltage and a number of other things. Revising table to reflect the relationship between the ratio of the measured sound pressure and the change in intensity expressed in dB produces, to **dB = 20 log**:

Ratio between Measurement 1 and 2	Equation	dB
1/2	dB = 20 log (1/2)	- 6 dB
1	dB = 20 log (1)	0 dB
2	dB = 20 log (2)	6 dB
10	dB = 20 log (10)	20 dB
100	dB = 20 log (100)	40 dB

1,000	dB = 20 log (1000)	60 dB
10,000	dB = 20 log (10000)	80 dB
100,000	dB = 20 log (100000)	100 dB
1,000,000	dB = 20 log (1000000)	120 dB
10,000,000	dB = 20 log (10000000)	140 dB
100,000,000	dB = 20 log (100000000)	160 dB
1,000,000,000	dB = 20 log (1000000000)	180 dB

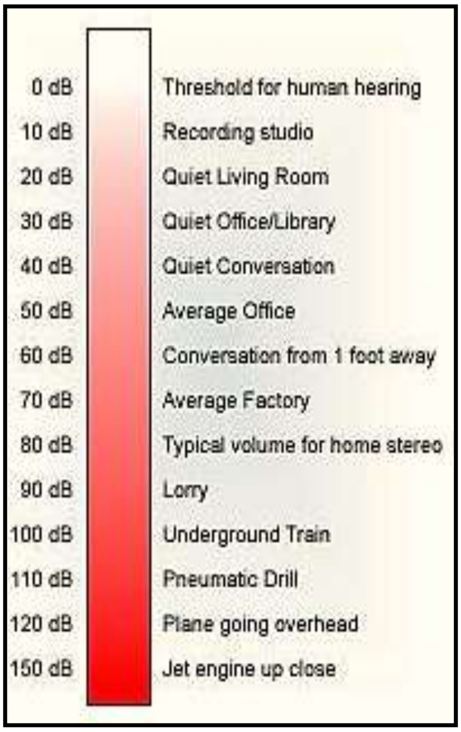
c) "Absolute" Sound Levels:

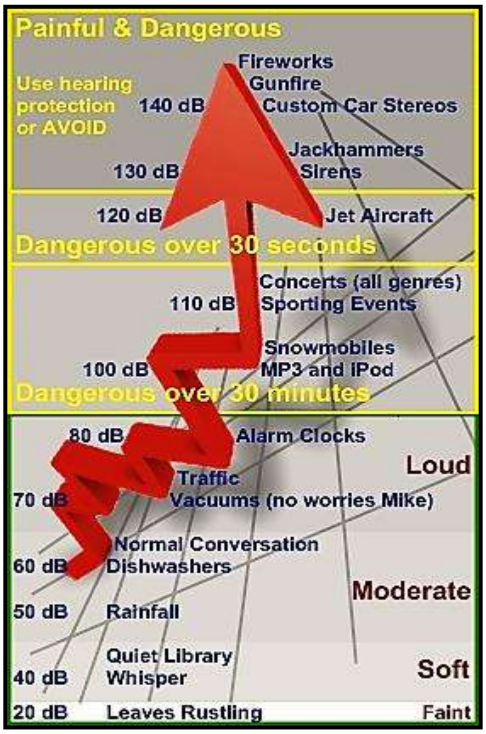
Whenever the decibel unit is used, it always represents the ratio of two values. Therefore, in order to relate different sound intensities it is necessary to choose a standard reference level. The reference sound pressure (corresponding to a sound pressure level of 0 dB) commonly used is that at the threshold of human hearing, which is conventionally taken to be 2×10 −5 Newton per square meter, or 20 micropascals (20 µPa). To avoid confusion with other decibel measures, the term dB (SPL) is used.

From the table it can be seen that **6 dB** equates to a doubling of the sound pressure. Alternately, reducing the sound pressure by 2, results in a **– 6 dB** change in intensity.

VII. NOISE MEASUREMENTS AND TESTS:

The **noise tests** may follow ISO-2204, ISO-R 1996 or any other standard requirements, according to the client. In any case the equipment distance, to measure the **noise level**, should be always **3.3 feet (~1.0 m)** and **sound pressure** the distance can be **10 feet (3.0 m)**.





Before starting measurement, the Inspector should choose the measurement scale of the sound analysis. Commonly, the equipment has **4 (four) measurement scales** for direct reading, (A, B, C, D), without filter, and another scale for the filter, capable of measuring the incident sound in a frequency very next the human hearing capacity, between 31 Hz and 16 KHz of the octave band.

The measurement scales **A an B** simulate the human hearing sound capacity between **40 dB and 85 dB.** The measurement scale **C** corresponds to sound beyond **85 dB** and scale **D** is restrict to aircrafts noises, then common scales are:

- dB (A) up to 55 dB
- dB (B) between 55 and 85 dB
- dB (C) above 85 dB

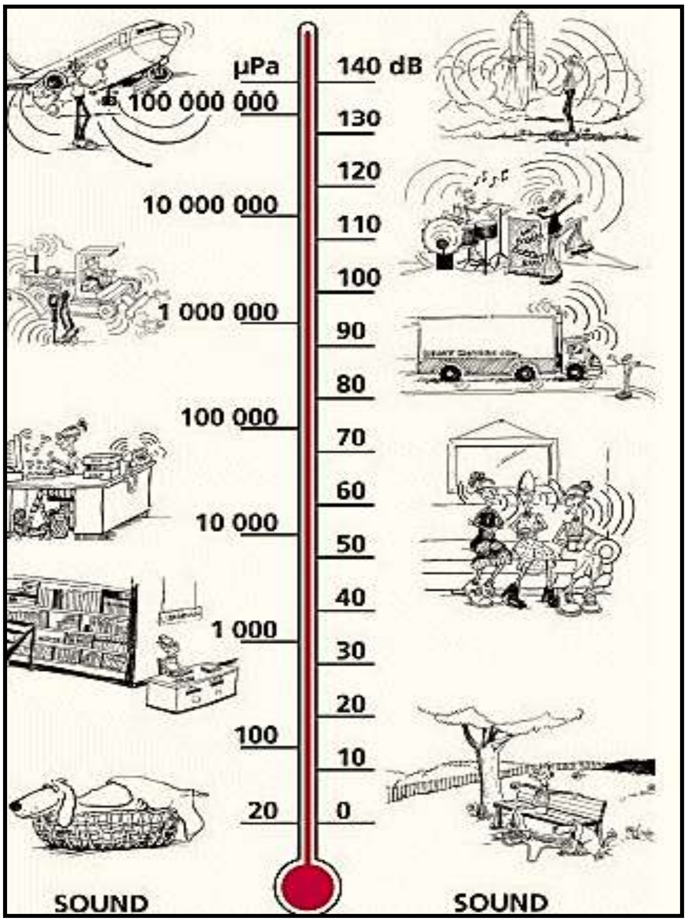
In critical noise environment the test Inspector should be aware of the distances between the noise measuring apparatus and the equipment being tested, since when the distance doubles. Considering a **distance**, the sound amplitude **falls in aproximately 6 dB**, in such a way, that when a **noise of 80 dB**, for example, measured at 1.0 m (3.3 feet) will be **reduced to 74 dB**. When the noise is measured at 2.0 m (6.6 feet) the noise level **falls to 68 dB**.

a) Sound Level Meter (SPL):

Sound level meter or SPL meter is a device that measures the **sound pressure** waves in decibels (dB-SPL) units, used to test and measure the loudness of the sound and for noise pollution monitoring. The **SI unit** for measuring **SPL is the pascal (Pa)** and in logarithmic scale the dB-SPL is used.

Note: Most sound level measurements relative to this level, means **1 Pa is equal an SPL of 94 dB,** or underwater, a reference level of **1 µPa** is used. These references are defined in **ANSI S1.1-1994**.

b) Conversion Table – SPL & dB



c) Table of common sound pressure levels in dB-SPL:

Sound type	Sound level (dB-SPL)
Hearing threshold	0 dB-SPL
Whisper	30 dB-SPL
Air conditioner	50-70 dB-SPL
Conversation	50-70 dB-SPL
Traffic	60-85 dB-SPL
Loud music	90-110 dB-SPL
Airplane	120-140 dB-SPL

d) Sound Pressure:

Sound pressure or acoustic pressure is the **local pressure deviation** from the ambient atmospheric pressure **caused by a sound wave**. In air, sound pressure can be measured using a microphone, and in water with a hydrophone. The SI unit for sound pressure is the pascal (Pa).

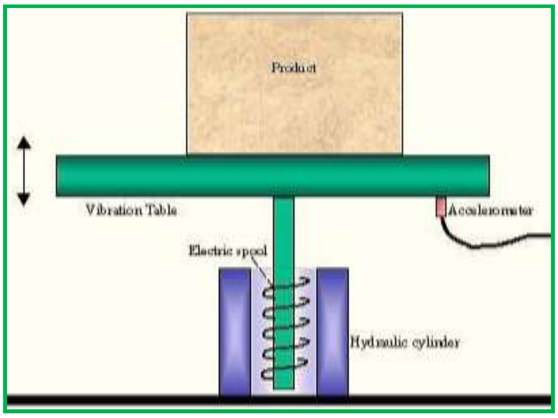
The commonly used "zero" reference **sound pressure in air or other** gases is **20 µPa RMS** (**root mean square – rms** is a statistical measure of the magnitude of a varying quantity), usually considered the **threshold of human hearing**, at **1 kHz** - or roughly the sound of a mosquito flying 3 m away.

VIII. VIBRATION MEASUREMENTS AND TESTS:

Vibration is the mechanical oscillations of an object about an equilibrium point, which may be regular such as the motion of a pendulum or random such as the movement of a tire on a gravel road. Vibration has two measurable quantities: **how far** (amplitude or intensity), and **how fast** (frequency) the object moves helps determine its vibrational characteristics. The main terms used to describe these movements are **frequency, amplitude and acceleration**.

The vibration equipment **calibration**: should be traceable to the National Institute of Standards and Technology **(NIST)** in accordance with ISO 10012-1/1992 and Sections 5.1 and 5.2 of ANSI S2.17-1980 "Technique of Machinery Vibration Measurement.

Frequency: A vibrating object moves back and forth from its normal stationary position. A complete cycle of vibration occurs when the object moves from one extreme position to the other extreme, and back again. The repetition rate of a periodic event, usually expressed in cycles per second (Hertz or Hz). One Hz equals one cycle per second (CPM).

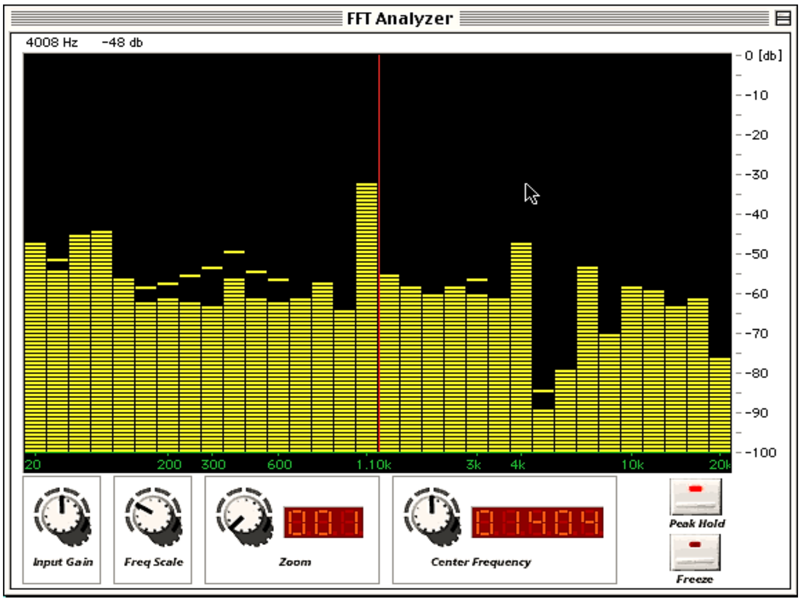


Amplitude: is the distance from the stationary position to the extreme position on either side. The intensity of vibration depends on amplitude. Usually expressed in meters (m) or feet (ft).

Acceleration: is when the speed of a vibrating object varies from zero to a maximum during each cycle of vibration. The vibrating object slows down as it approaches the extreme where it stops, and then moves in the opposite direction toward the other extreme. Usually expressed in m/s^2.

- **Measurement System Accuracy:**

Sophisticated and common vibration equipment systems are used to take vibration measurements for **machine certification and acceptance.** All of them should be calibrated according to a standard procedure or a template and have a measurement system amplitude accuracy over the selected frequency range, as the FFT analyser, shown below:



- **FFT Analyser:**

The **FFT (Fast Fourier Transform) Analyzer** shall be capable of a line resolution bandwidth Df = 300 CPM for the frequency range specified for machine certification unless this restriction would result in less than 400 lines of resolution, in which case the requirement defaults to 400 lines of resolution. (Higher resolution may be required to resolve "Side Bands," or in Band 1 to resolve machine vibration between 0.3X and 0.8X Running Speed.).

- For displacement and velocity measurements –l0% or –1 dB.
- For acceleration measurements –20% or –1.5 dB.
- The Dynamic Range shall be a minimum of 72 dB.
- The FFT analyzer shall be capable of linear non-overlap averaging.

- **Accelerometers:**

Accelerometers are used for data certification and acceptance. Accelerometers should be selected in such a way that the **minimum frequency (F) and maximum frequency (Fmax)** are within the usable frequency range of the transducer and can be accurately measured (recommendations of the manufacturer and/or Section 6.3, ANSI S2.17-1980).

The mass of the accelerometer and its assembly minimal influence on the frequency response of the system over the selected measurement range. **Typical mass** of accelerometer and mounting **should not exceed 10 % of the dynamic mass** of its assembly structure). The integration is acceptable to convert acceleration measurements to velocity or displacement, or to convert velocity to displacement.

- **Vibration Measurement Axis Directions:**

Axial Direction (A): shall be parallel to the rotational axis of the machine (see figures below).

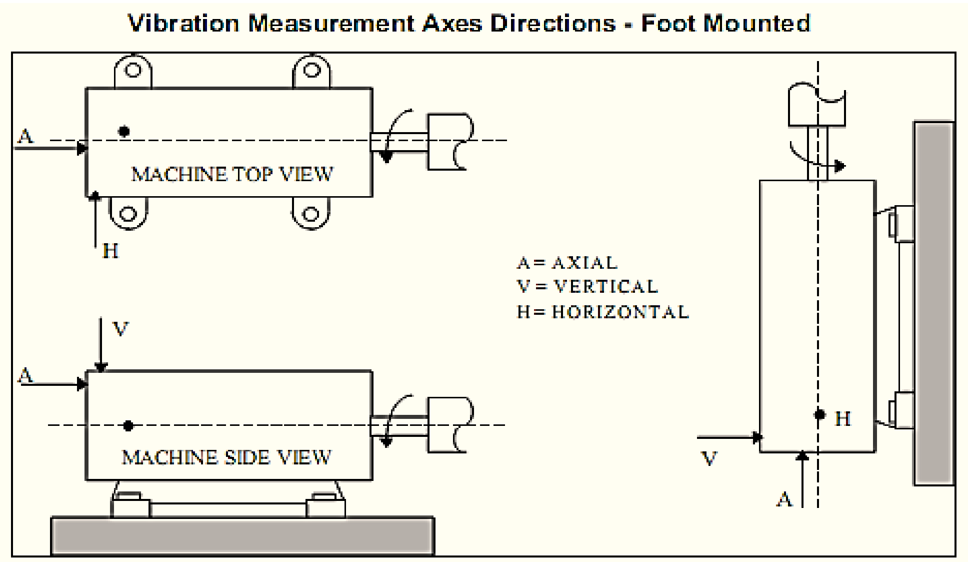
Radial Direction (R): shall be at 90° (perpendicular) relative to the shaft (rotor) centerline.

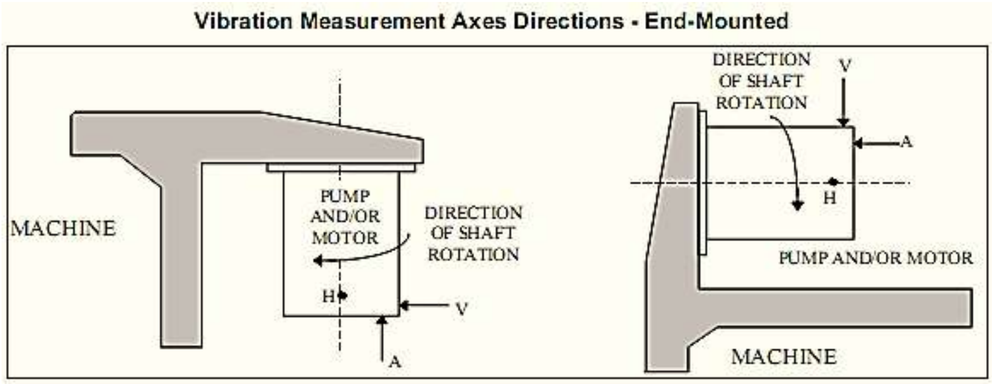
Vertical Direction (V): shall be in a radial direction on a machine surface opposite the machine mounting plate.

Horizontal Direction (H): shall be in a radial direction, at a right angle (90°) from the vertical readings or in the direction of the shaft (rotor) rotation (see figures below).

Other Direction: Any radial direction other than Horizontal or Vertical.

For motors or pumps end mounted, vertical readings shall be taken in a radial direction relative to axial readings on a surface opposite the machine to which the motor or pump is attached (see below).

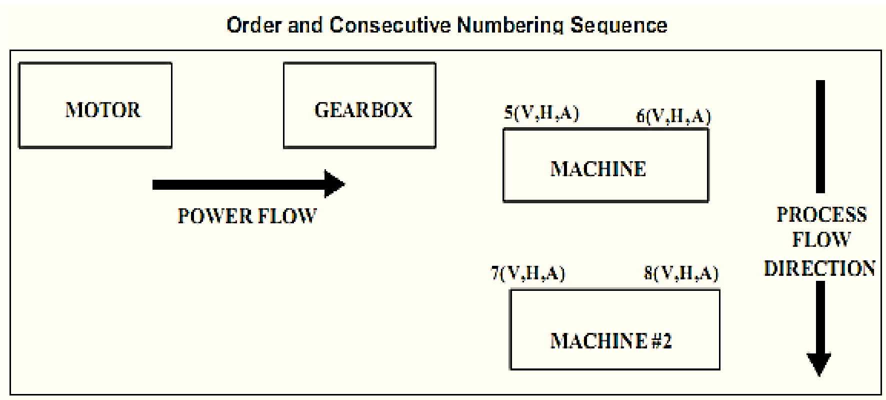




Location Identification: Measurement locations shall be numbered consecutively from 1 to N in the direction of power flow per the following:

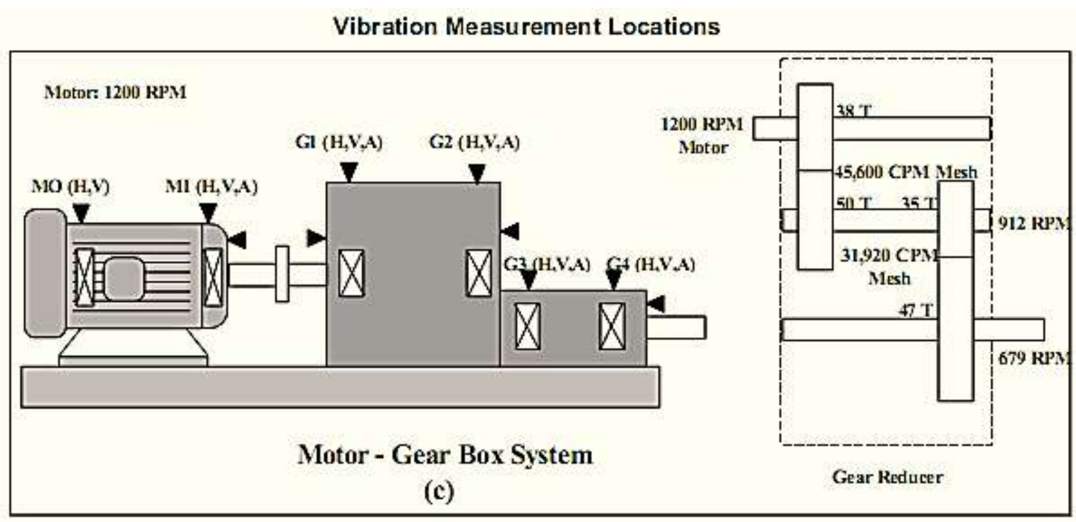
Position 1: designates the "out-board" Starting Power Point bearing location of the driver unit.

Position N: designates the bearing location at the "terminating" Power Point bearing location.



- **Machine Assembly:**

When a machine is be tested as an individual unit (e.g. motor, spindle, etc.) the machine must be mounted to be tested as an **assembled unit** (e.g. motor/pump, motor/fan, etc.), the machine mounting conditions shall be, as equivalent as possible, to those to be encountered upon installation at site.



- **Bearings Vibration Tests:**

Bearings are the machine components that support and **transfer the forces** from the rotating element to the machine frame. This results in the perception that bearings are inherently a reliability problem due to the fact that only 10% to 20% of rolling element bearings achieve their design life.

One of the leading causes of premature rolling element bearing failure is parasitic load due to excessive vibration caused by imbalance and misalignment. The resulting parasitic loads result in increased dynamic loads on the bearings. The design formulas (SKF, 1973) used to calculate theoretical rolling element bearing life for **Ball Bearings and Roller Bearings** are:

a. Ball Bearings

$$L_{10}\ Life\ Hours = \left(\frac{16{,}667}{RPM}\right) X \left(\frac{C}{P}\right)^3$$

b. Roller Bearings

$$L_{10}\ Life\ Hours = \left(\frac{16{,}667}{RPM}\right) X \left(\frac{C}{P}\right)^{\frac{10}{9}}$$

Where, **L10** is the **number of hours** 90% of a group of bearings should attain or exceed under a constant load (P) prior to fatigue failure; **C** is the **bearing load** which will result in a life of one million revolutions; and **P** is the **actual bearing load**, static and dynamic. **C** is obtained from a **bearing manufacturer's catalogue** and **P is calculated** during equipment design.

As shown, bearing life is inversely proportional to speed and more significantly, inversely proportional to the third power of load for ball and to the 10/9 power for roller bearings.

- **Balance Calculations:**

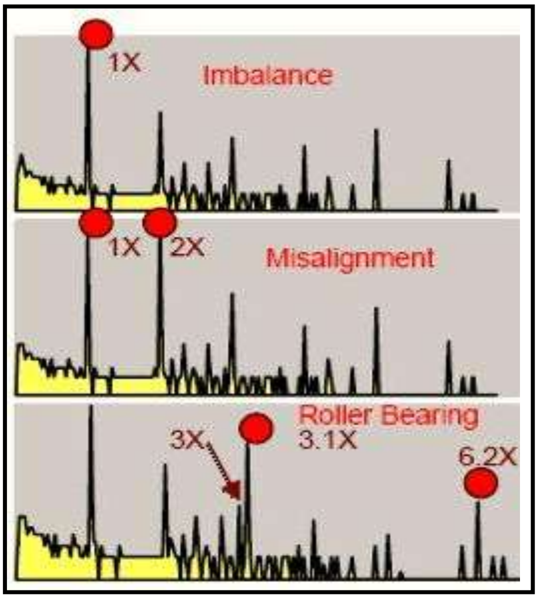
Precision balance of **motors, rotors, pump impellers and fans** are the most critical and cost effective techniques for achieving increased bearing life and resultant equipment reliability. It is not usually sufficient to simply perform a **single plane balance of a rotor** to a level of **0.10 in/sec**, is it sufficient to balance a rotor until it **achieves low vibration** levels.

Precision balance methods should also include the calculation of residual imbalance. The following equation can be used to calculate residual imbalance:

$$|U_r| = \frac{V_r}{V_e}\, x\, |M|$$

Where:

Ur = amount of residual imbalance,
Vr = actual imbalance,
Ve = trial mass imbalance,
M = trial mass.



- **Effect of Imbalance:**

Vibration analysis, properly applied, allows the **detection of small developing mechanical defects** long before they become a threat to the integrity of the machine, and thus provides the necessary lead time to suit the needs and schedules of the plant operators / management. In this way, plant management has control over the machines, rather than the other way around.

Example:

Consider a rotor turning at **3600 RPM with 1 oz**. of unbalance on a **12" radius**. Calculate the amount of **centrifugal force** due to imbalance as shown below, where:

$$F = mA = mr\,\omega^2 = \frac{mr(2\pi f\,)^2}{g} = 0.102\,mrf^2$$

F = Force
m = imbalance (lbs)
r = radius of imbalance (in)
f = rotational speed (Hz)
g = 386.4 in/sec^2

Substitute 1 oz. (1/16 lb.), 12", 3600 RPM (60 Hz):

$$F = 0.102\,x\,(\frac{1}{16})\,x\,(12)\,x\,(60\,)^2 = 275\ lbs.$$

Thus, **1 oz**. of imbalance on a rotor **12" radius at 3600 RPM** creates an effective **centrifugal force of 275 lbs**, as calculated above.

Now calculate the effect of this weight on bearing life. Suppose that the bearings were designed to support a **1000 lb.** rotor. The calculated bearing life is less than 50% of the design life as shown below.

$$Actual\ L_{10}\ Life = (Design\ L_{10}\ Life)\,x\,(\frac{1000}{1000+275}\,)^3$$
$$= 0.48\ Design\ L_{10}\ Life$$

The table below contains the **ISO1940/1-1986 balance quality grades** for various groups of representative rigid rotors. The following equations and discussion of permissible imbalance is based on ISO 1940/1, *Mechanical vibration—Balance quality requirements of rigid rotors*.

Balance Quality Grade	Product of The Relationship $(e_{per}\ x\ \ )$ [1,2] mm/s	Rotor Types—General Examples
G4,000	4,000	Crankshaft/drives[3] of rigidly mounted slow marine diesel engines with uneven number of cylinders[4]
G1,600	1,600	Crankshaft/drives of rigidly mounted large two-cycle engines
G630	630	Crankshaft/drives of rigidly mounted large four-cycle engines Crankshaft/drives of elastically mounted marine diesel engines
G250	250	Crankshaft/drives of rigidly mounted fast four cylinder diesel engines[4]
G100	100	Crankshaft/drives of rigidly mounted fast diesel engines with six or more cylinders[4] Complete engines (gas or diesel) for cars, trucks, and locomotives[5]
G40	40	Car wheels, wheel rims, wheel sets, drive shafts Crankshaft/drives of elastically mounted fast four-cycle engines (gas or diesel) with six or more cylinders Crankshaft/drives of engines of cars, trucks, and locomotives
G16	16	Drive shafts (propeller shafts, cardan shafts) with special requirements Parts of crushing machines Parts of agricultural machinery Individual components of engines (gas or diesel) for cars, trucks and locomotives Crankshaft/drives of engines with six or more cylinders under special requirements
G6.3	6.3	Parts of process plant machines Marine main turbine gears (merchant service) Centrifuge drums Paper machinery rolls: print rolls Fans Assembled aircraft gas turbine rotors

Balance Quality Grade	Product of The Relationship (e_{per} x)[1,2] mm/s	Rotor Types—General Examples
G6.3	6.3	Flywheels Pump impellers Machine-tool and general machinery parts Medium and large electric armatures (of electric motors having at least 80 mm shaft height) without special requirements Small electric armatures, often mass produced, in vibration insensitive applications and/or with vibration isolating mountings Individual components of engines under special requirements
G2.5	2.5	Gas and steam turbines, including marine turbines (merchant service) Rigid turbo-generator rotors Computer memory drums and discs Turbo-compressors Machine-tool drives Medium and large electric armatures with special requirements Small electric armatures not qualifying for one or both of the conditions specified for small electric armatures of balance quality grade G6.3 Turbine-driven pumps
G1	1	Tape recorder and phonograph (gramophone) drives Grinding-machines drives Small electric armatures with special requirements
G0.4	0.4	Spindles, disc, and armatures of precision grinders Gyroscopes

Table 3–3. Balance Quality Grades for Various Groups of Representative Rigid Rotors (ISO 1940/1-1986)

Notes:

1. For allocating the permissible residual unbalance to correction planes.

2. A crankshaft/drive is an assembly which, includes a crankshaft, flywheel, clutch, pulley, vibration damper, rotating portion of connecting rod, etc.

3. For the purposes of this part of ISO 1940, slow diesel engines are those with a piston velocity of less than 9 m/s; fast diesel engines are those with a piston velocity of greater than 9 m/s.

4. In complete engines, the rotor mass comprises the sum of all masses belonging to the crank-shaft/drive described in note 3 above.

- **Machine Alignment:**

Coupled Shafts Aligment: Coupled shaft alignment is the positioning of two or more machines so that the rotational centerlines of their shafts are colinear at the coupling center under operating conditions.

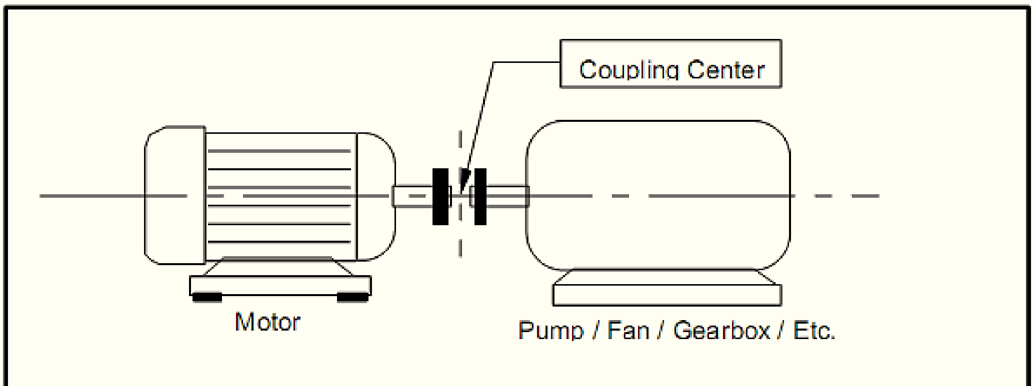
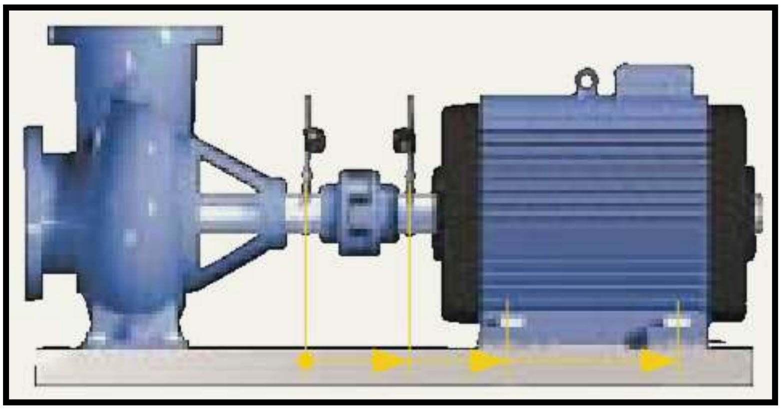


Figure 1 - Coupled Shafts Alignment

Laser Shaft Alignment: The Laser Alignment System is used for Coupled Shafts Alignment for either a combined laser emitter and laser target detector unit or separate units for its laser emitter and laser target detector.

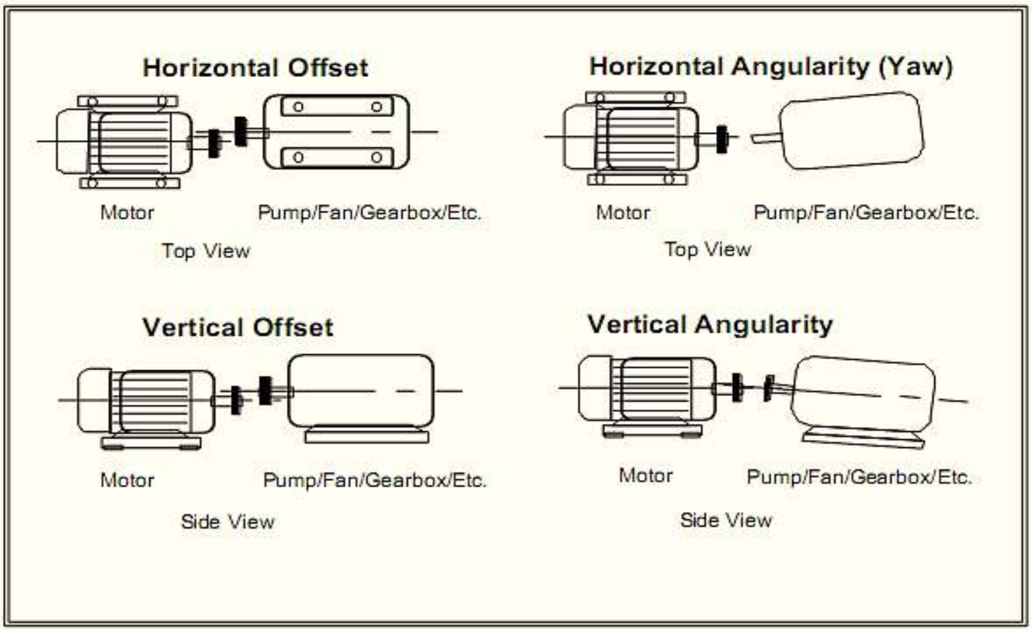


Shaft Alignment Tolerances: All shaft-to-shaft centerline alignments shall be within the tolerances specified in the table below, unless more precise tolerances are specified by the machine manufacturer or by the purchasing engineer for special applications.

	RPM	TOLERANCE SPECIFICATION
SOFT FOOT	ALL	<0.002 inch (0.0508 mm) at each foot

	RPM	HORIZONTAL & VERTICAL PARALLEL OFFSET	ANGULARITY/GAP Inch/10 inch (mm/254 mm)
SHORT COUPLINGS			
	<1000	0.005 in (1.2700 mm)	0.015 in (0.3810 mm)
	1200	0.004 in (1.0160 mm)	0.010 in (0.2540 mm)
	1800	0.003 in (0.7620 mm)	0.005 in (0.1270 mm)
	3600	0.002 in (0.5080 mm)	0.003 in (0.0762 mm)
	7200	0.001 in (0.2540 mm)	0.0025 in (0.0635 mm)

Axial Shaft Play: must be no greater than 0.125 inch (3.175 mm). Accommodation of the end movement must be done without inducing abnormal loads in the connecting equipment.

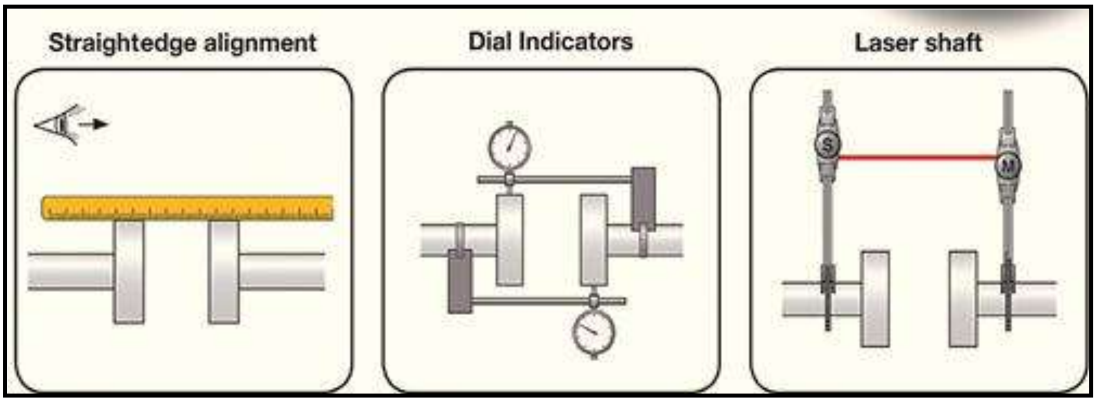


The table below provide limitations and effect of **misalignment** on rolling element bearings. The maximum acceptable misalignment is based on experience data in bearing **manufacturers' catalogs**.

Alignment Related Tolerances (General Motors, 1993)

Parameter	Tolerance
Soft Foot	0.002" max
Foot Centerline Deformation (No load to full load)	0.001" max
Single Steel Base Plate Thickness	1.0" min
Foot Movement Caused by Pipe Flange Tightening	0.002" max
Total Shim Pack	5
Minimum Shim Pack Size	0.125" min
Axial Shaft Play	0.125" max

The use of **precision equipment** and methods, such as **reverse dial and laser systems** to bring alignment tolerances within precision standards, is recommended, as shown below:



Contrary to popular belief, both **laser alignment** and **reverse dial indicator** equipment offer equal levels of precision; however, laser alignment is considerably easier and quicker to learn and use. The recommended specifications for precision alignment are provided in the table shown below:

Recommended Coupled Alignment Tolerances (General Motors, 1993)

Coupling Type	Maximum Speed (RPM)	Tolerance	
		Horizontal & Vertical Parallel Offset (IN.)	Angularity (Inch/10 inch of Coupling Dia.)
Short Coupling	600	0.005	0.010
	900	0.0053	0.007
	1200	0.0025	0.005
	1800	0.002	0.003
	3600	0.001	0.002
	7200	0.0005	0.001
Coupling with Spacer (Meåsurement is per inch of spacer length)	600	0.005	N/A
	900	0.0018	N/A
	1,200	0.0012	N/A
	1,800	0.0009	N/A
	3,600	0.0006	N/A
	7,200	0.00015	N/A

- **Alignment Effects:**

The forces of vibration from misalignment also **cause gradual deterioration** of seals, couplings, drive windings, and other rotating elements where close tolerances exist. Based on data from a petrochemical industry survey, precision alignment practices achieve:

- Average bearing life increases by a factor of 8.0.
- Maintenance costs decrease by 7%.
- Machinery availability increases by 12%.

IX. PUMP PERFORMANCE AND TESTS:

A critical function of any pump manufacturer is the performance testing of their product to ensure that it meets design specifications. Test facilities are designed to provide performance and **NPSHR** tests in accordance with the latest edition of **API 610** or the Hydraulic Institute.

Test Softwares allow all parameters to be monitored and controlled from a central control station, providing precise control to achieve and maintain specific operating conditions, so that data from precision electronic sensors can be collected and recorded for use in verifying pump performance.

Variable Frequency Drive: is always utilized to maintain precise speed control on units to achieve a controlled acceleration up to synchronous operating speed. Flow is commonly measured by **calibrated magnetic** flow meters installed in metering runs, while calibrated electronic sensors measure pressure at compliant metering spools connected to the suction and discharge nozzles of the pump. **NPSH** testing is performed using vacuum suppression method.

- **Mechanical Seals:**

Pumps provided with mechanical seals should be tested **with its own seal** and no leaks shall be allowed. In case a leak is confirmed during the test, the mechanical seal should be dismounted, analysed about the wearing and replaced.

- **Drive Motor:**

When it is possible, the pump should be tested with **its own motor**, since there is the possiblity to use the same operation conditions, such as the same flow fluid and power consumption. It is also necessary to correct fluid viscosity, flow curves, manometric height and hydraulic efficiency using defined tables or a mathematical abacus.

- **Brake Horse Power (BHP) Evaluation:**

The best way to define a pump efficiency is to measure the consumed power during its performance test. The measured power should not exceed 4% the specified value, considering some limitations of electrical energy in the work site. The **BHP** can be evaluated by two (2) methods:

- ✓ With a voltmeter and a wattmeter;
- ✓ Without instruments.

a) With a voltmeter and a wattmeter:

The Inspector shall read each flow point, the electric voltage and current **using a voltmeter and a wattmeter**. Then, he should find in the calibrated motor performance curve, its efficiency and the power factor in function of the measured current, using the following formula below:

$$P = V \cdot I \cdot \cos\theta \cdot \eta \, \frac{\sqrt{3}}{1000}$$

P = BHP Power
V = Electric Voltage
I = Electric Current
□ = Calibrated Motor Efficiency
Cos θ = Power Factor

Example:

During a pump performance test, the following electrical variables below were found, for power evaluation of an electric motor 20 HP, 440V / II poles (remember 20 HP = 14.9 kW):

V = 422 V
I = 21 A
□ = 0.84
Cos θ = 0.89

P = 422 x 21 x 0.89 x 0.84 x 0.001732 =

$\boxed{\mathbf{P = 11.46\ kW}}$

Obs.: Then **11.46 kW** is the correct power for this electric motor using the above electrical conditions.

b) Without instruments:

In case there is **no possibility** to have a voltmeter, wattmeter and the calibrated curve is not available, it is possible to estimate the consumed power associating the voltage, current and nominal motor power. Due this calculation is not accurate, the power evaluation can be done using the formula below:

$$\boxed{P = \frac{V_t}{V_n} \cdot \frac{I_t}{I_n} \cdot P_n}$$

Where:

Vt = Estimated available tension
Vn = Nominal electric motor tension
It = Estimated available current
In = Nominal electric motor current
Pn = Nominal power

Example:

During a power evaluation with an electric motor 20 HP, 440V and 30A, in the operation point was verified the following electric variables:

Vt = 422 V
It = 21 A

$$\mathbf{P = \frac{422}{440} \times \frac{21}{30} \times 20 =}$$

P = 13.42 HP

The hydraulic efficiency can also be calculated. The **Brake Horsepower (BHP)** is the actual horsepower delivered to the pump shaft, defined as follows:

$$\mathbf{BHP = \frac{Q \times H \times SG}{3960} \times P\eta =}$$

Where:

Q = Capacity in gallons per minute
H = Total Differential Head in absolute feet
SG = Specific Gravity of the liquid
Pη = Pump efficiency as a percentage

Note: The **constant (3960)** is the number of foot-pounds in **one horsepower (33,000)** divided by the weight of **one gallon of water (8.33 pounds)**.

- **Common Pumping Tests:**

- Discharge test pressures;
- Supply tank rated from full vacuum;
- Vibration, torque, temperature and speed measuring equipment;
- Variable Frequency Drive for precise speed control;
- Soft start for low impact motor starting;
- Calibrated magnetic flow meters;
- Torque couplings provide data to calculate brake horsepower and efficiency;
- NPSHR test accomplished through the use of a vacuum pump;
- Pumping test procedures based on API 610 criteria or meet specific customer requirements.

- **Evaluation of NPSH:**

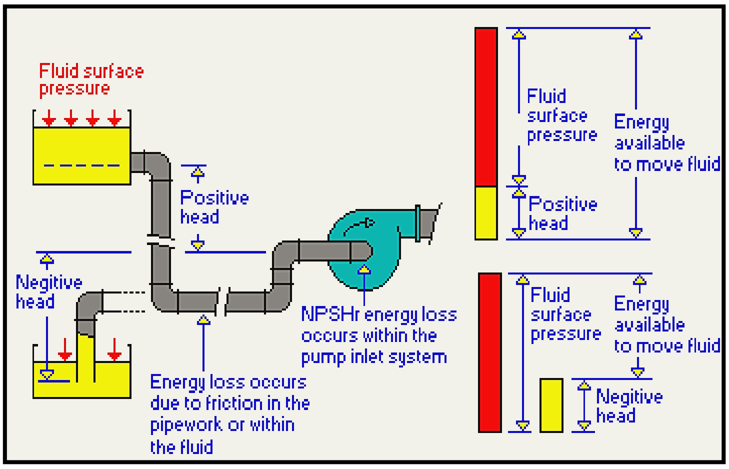
The term **NPSH** means **Net Positive Suction Head**. The motive to calculate the NPSH of any pump is to avoid the cavitation or corrosion of the parts during the normal process. The **main concepts** of **NPSH** to be understood are the the **NPSHr (required)** and **NPSHa (available).**

NPSHr: can be **found in a manufacturing catalog of pumps**, a technician or an engineer is choosing to apply in a project or installation. The manufacturer always shows the graphic curves of all line pumps manufactured by the company, indicating the **required NPSH** for each product.

NPSHa: is the normal calculation the technician or the engineer has to perform to find which of pump, from that manufacturing catalog, will better fit in his project or installation. Then, to calculate the available NPSH of a pump is necessary to know the following concepts:

NPSHa (available) **> NPSHr** (required).

- **Calculation of the NPSH Process:**



As explained above the calculation is for the **NPSHa.** The **NPSHa** (converted to head) is:

NPSHa = + - Static Head + Atmospheric Pressure Head - Vapor Pressure – Friction Loss in piping, valves and fittings:

NPSHa = +- H + Pa – Pv - Hf

H = Static Suction Head (positive or negative), in feet
Pa = Atmospheric pressure (psi x 2.31/Sg), in feet
Pv = Vapor pressure (psi x 2.31/Sg), in feet.
Hf = See tables indicating friction loss. Fittings friction loss is (K x $v^2/2g$), in feet.

Example:

1) Find the NPSHa from below data:

Cold water pumping, **Q** =100 gpm @ 68°F;
Flow velocity, **v** = 10 ft/s (maximum);
Specific gravity, **Sg** = 1.0 (clean water).
Steel Piping – (suction and discharge) = 2 inch diameter, total length10 feet, plus 2 x 90° elbow;

H = Liquid level is above pump centerline = + **5 feet**
Pa = Atmospheric pressure = **14.7 psi** - the tank is at sea level
Pv = Water vapor pressure at 68°F = **0.339 psi**.

According to pump manufacturer the **NPSHr** (required), as per the pump curve) = **24 feet**.

Using the above formula:

NPSHa = **+- H + Pa – Pv – Hf**

H - Static head = **+5 feet**
Pa - Atmospheric pressure = psi x 2.31/Sg. = **14.7 x 2.31/1.0 = +34 feet absolute**
Pv – Water vapor pressure at 68°F = psi x 2.31/Sg = **0.339 x 2.31/1.0 = 0.78 feet**
Hf - 100 gpm - through 2 inches pipe shows a loss of **36.1 feet** for each **100 feet of pipe**, then:

Piping friction loss = $\mathbf{Hf_1}$ = 10 ft / 100 x 36.1 = **3.61 feet**

Fittings friction loss = $\mathbf{Hf_2}$ = **K x $v^2/2g$** = $\dfrac{0.57 \times 10^2}{2 \times 32.17}$ (x 2) = **1.77**

Total friction loss for piping and fittings **= Hf = (Hf_1 + Hf_2) = 3.61 + 1.77 = 5.38 feet.**

NPSHa (available) = +- H + Pa – Pv – Hf =

NPSHa (available) = + 5 + 34 - 0.78 – 5.38 =

NPSHa (available) = 32.34 feet (NPSHa) > 24 feet (NPSHr), so, the system has plenty to spare.

X. BEARING TEMPERATURE EVALUATION:

We define **temperature** taken at the **bearing cap surface**. The normal procedure is that an operating temperature **at the bearing cap** can not exceed **175F (80º C)**, as long as the temperature has leveled out and not still rising.

Temperatures up to **200F (90º C)** can also be **satisfactory**, but **further investigation** is recommended to determine the cause of the higher bearing operating temperature. In pumps for boiler feed applications, handling hot water, above **boiling point** and other high temperature applications, the bearing temperature may approach **this higher limit** from heat transfer along the shaft and still perform satisfactorily.

Special consideration of **lubricants**, **water cooling** or special bearing clearances may be required for **pumping temperatures** above **250F (120º C)** on general-purpose bearings before heat treating for dimensional stability is recommended.

Excessive lubrication of bearings should **be avoided** as it may result in **overheating** and possible bearing failure. Under normal applications, adequate lubrication is assured if the **amount of grease** is maintained at **1/3 to ½ the capacity** of the bearing and adjacent space surrounding it. We recommend using a **premium lubricant** equal to Number 2 (polyurea base).

These temperatures apply to **grease-lubricated** as well as **oil-lubricated** bearings. New bearings often require a break-in **period of up to 100 hours**. During this time, temperatures and noise levels can be slightly elevated. However, these levels should decrease somewhat after this break-in period.

Siemens, Westinghouse, and GE **elliptical friction bearings** typically alarm up to a temperature **at 265°F (130ºC),** well privileged to work on such currently alarm. For **cooling water pumps** and **open drip proof motors** bearing housings the range is commonly **<110°F (<45ºC)**. For Totally Enclosed Fan Cooled Motors (TEFC motors) bearing housings the range is **140°F ~ 180°F (60ºC ~ 80ºC).**

- **Common Bearing Temperatures:**

a) Mineral-oil-lubricated bearings:

- run temperature: 80 °C
- alarm temperature: 90 °C
- shutdown temperature: 100 °C

b) Synthetic-oil-lubricated bearings:

- run temperature: 110 °C
- alarm temperature: 120 °C
- shutdown temperature: 130 °C

It is important to define where the bearing temperature is taken. The design temperature at the **bearing surface will be higher** than at the **outside surface of the bearing cap**, possibly **10 to 15°F (-9°C @ -12 ºC)** difference.

- **Pump Bearing Temperature:**

The maximum operating temperature for a ball bearing in a pump is the result of a number of factors, not limited to, but including some or all of the following:

1) Operating speed;
2) Shaft loading;
3) Type of lubrication;
4) Amount of lubricant in the bearing;
5) Pump alignment;
6) Pumping temperature;
7) Ambient temperature;
8) Bearing fits;
9) Continuous or on-off service;
10) Location of the pump duty point on the performance curve

XI. FAILURE DIAGNOSTIC DETECTION:

The advent of micro-processor based valve **instruments in-service diagnostics** capabilities has allowed companies to redesign their control valve maintenance work practices. More specifically, in-service diagnostics oversee:

1. Instrument Air Leakage: This diagnostic can detect both positive (supply) and negative (exhaust) air mass flow not only to detect leaks in the actuator or related tubing, but also much more difficult problems. For example, in piston actuators, the air mass flow diagnostic can detect leaking piston seals or damaged O-rings.

2. Supply Pressure: This in-service diagnostic will detect low and high supply pressure readings for adequate supply pressure to detect and quantify droop in the air supply during large travel excursions. This is particularly helpful in identifying supply line restrictions.

3. Travel Deviation and Relay Adjustment: The travel deviation diagnostic is used to monitor actuator pressure and travel deviation from setpoint and identify a stuck control valve, active interlocks, low supply pressure or shifts in travel calibration.

4. Instrument Air Quality: The I/P and relay monitoring diagnostic can identify problems such as plugging in the I/P primary or in the I/P nozzle, instrument diaphragm failures, I/P instrument O-ring failures, and I/P calibration shifts, as well, in identifying problems from contaminants in the air supply and from temperature extremes.

- **Types of Protection:**

The types of protection commonly used for instruments are:

1. Dust Ignition-proof: A type of protection that excludes ignitable amounts of dust will not allow arcs, sparks or heat otherwise generated or liberated inside the enclosure to cause ignition of exterior accumulations or atmospheric suspensions of a specified dust.

2. Explosion-proof: A type of protection that utilizes an enclosure that is capable of withstanding an explosion of a gas or vapor within it and of preventing the ignition of an explosive gas or vapor that may surround it.

3. Intrinsically Safe: A type of protection in which the electrical equipment under normal or abnormal conditions is incapable of releasing sufficient electrical or thermal energy to cause ignition of a specific hazardous atmospheric mixture.

4. Non-Incendive: A type of protection in which the equipment is incapable, under normal conditions, of causing ignition of a specified flammable gas or vapor-in-air mixture due to arcing or thermal effect.

- **NEC Hazardous Location Classification:**

Hazardous areas procedures are classified by **class, division, and group**. The method was introduced into the **1996 edition of the NEC** as an alternate method, but it is not yet in use. The zone method is common in Europe and most other countries.

- **Class**: defines the general nature of the hazardous material in the surrounding atmosphere.

Class I. Locations in which flammable gases or vapors are, or may be, present in the air in quantities sufficient to produce explosive or ignitable mixtures.

Class II. Locations that are hazardous because of the presence of combustible dusts.

Class III. Locations in which easily ignitable fibers or flyings may be present but not likely to be in suspension in sufficient quantities to product ignitable mixtures.

- **Division**: The Division defines the probability of hazardous material being present in an ignitable concentration in the surrounding atmosphere.

Division 1: Locations in which the probability of the atmosphere being hazardous is high due to flammable material being present continuously, intermittently, or periodically.

Division 2: Locations that are presumed to be hazardous only in an abnormal situation.

- **Group:** The Group defines the hazardous material in the surrounding atmosphere. The specific hazardous materials within each group and their automatic ignition temperatures can be found in Article 500 of the NEC and in NFPA 497M. Groups A, B, C and D apply to Class I, and Groups E, F and G apply to Class II locations. The following definitions are from NEC:

Group A: Atmospheres containing acetylene.

Group B: Atmospheres containing hydrogen, fuel and combustible process gases containing more than 30 percent hydrogen by volume, or gases or vapors of equivalent hazard such as butadiene, ethylene oxide, propylene oxide, and acrolein.

Group C: Atmospheres such as ethyl ether, ethylene, or gases or vapors of equivalent hazard.

Group D: Atmospheres as acetone, ammonia, benzene, butane, cyclopropane, ethanol, gasoline, hexane, methanol, methane, natural gas, naphtha, propane, or gases or vapors of equivalent hazard.

Group E: Atmospheres containing combustible metal dusts, including aluminum, magnesium, and their commercial alloy, or other combustible dusts whose particle size, abrasiveness, and conductivity present similar hazards in the use of electrical equipment.

Group F: Atmospheres containing combustible carbonaceous dusts, including carbon black, charcoal, coal, or dusts that have been sensitized by other materials so that they present an explosion hazard.

Group G: Atmospheres containing combustible dusts not included in Group E or F, including flour, grain, wood, plastic, and chemicals.

The **NEC** states that any equipment that does not exceed a maximum surface temperature of 100 °C (212 °F) is not required to be marked with the temperature code. Therefore, when a temperature **code is not specified**, it is assumed to be **T5**.

- **NEMA Hazardous Locations:**

Two of four enclosure ratings for classified locations are described as follows in NEMA 250:

Type 7: (Class I, Division 1, Group A, B, C or D, Indoor hazardous location, Enclosure): For indoor use in locations classified as Class I, Division 1, Groups A, B, C or D as defined in the NEC and shall be marked to show class, division, and group. Capable of withstanding the pressures resulting from an internal explosion of specified gases.

Type 9: (Class II, Division 1, Groups E, F or G, Indoor hazardous location, Enclosure): Intended for use in indoor locations classified as Class II, Division 1, Groups E, F and G as defined in the NEC and shall be marked to show class, division, and group. Enclosures shall be capable of preventing the entrance of dust.

- **NEMA Enclosure Ratings:**

Enclosures **may be tested** to determine their ability to prevent the ingress of liquids and dusts. In the United States, equipment is tested to NEMA 250. Some of the more common enclosure ratings defined in NEMA 250 are as follows.

Type 3R: (Rain-proof, Ice-resistance, Outdoor enclosure): Intended for outdoor use primarily to provide a degree of protection against rain, sleet, and damage from external ice formation.

Type 3S: (Dust-tight, Rain-tight, Ice-proof, Outdoor enclosure): Intended for outdoor use primarily to provide a degree of protection against rain, sleet, windblown dust, and to provide for operation of external mechanisms when ice ladened.

Type 4: (Water-tight, Dust-tight, Ice-resistant, Indoor or outdoor enclosure): Intended for indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water, hose-directed water, and damage from external ice formation.

Type 4X: (Water-tight, Dust-tight, Corrosion resistant, Indoor or outdoor enclosure): Intended for indoor or outdoor use primarily to provide a degree of protection against corrosion, windblown dust and rain, splashing water, and hose-directed water, and damage from external ice formation.

- **NEMA and IEC Enclosure Rating Comparison:**

The following table provides an equivalent conversion from **NEMA** to **IEC IP** designations. The NEMA types meet or exceed the test requirements for the associated IEC classifications.

IEC Temperature Codes

TEMPERATURE CODE	MAXIMUM SURFACE TEMPERATURE	
	°C	°F
T1	450	842
T2	300	572
T3	200	392
T4	135	275
T5	100	212
T6	85	185

Conversion of NEMA Types to IEC IP Codes

NEMA Type	IEC IP
3	IP54
3R	IP14
3S	IP54
4 and 4X	IP65

Ingress Protection (IP) Codes

First Numeral Protection against solid bodies	Second Numeral Protection against liquid
0 No protection	0 No protection
1 Objects greater than 50 mm	1 Vertically dripping water
2 Objects greater than 12.5 mm	2 Angled dripping water (75° to 90°)
3 Objects greater than 2.5 mm	3 Sprayed water
4 Objects greater than 1.0 mm	4 Splashed water
5 Dust-protected	5 Jetting
6 Dust-tight	6 Powerful jetting
- -	7 Temporary immersion
- -	8 Permanent immersion

- **Temperature Codes:**

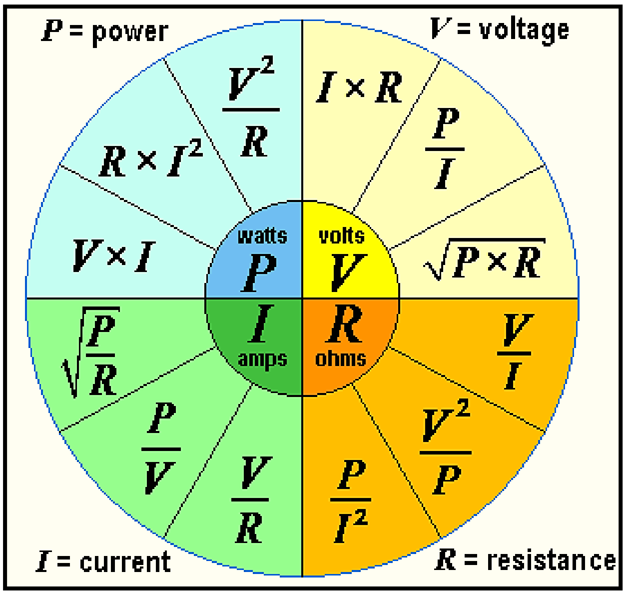
The conditions under which a hot surface will ignite, depend on surface area, temperature and gas concentration. Tested equipment indicates the maximum surface temperature, as shown below:

Class 1	Division 1	Groups ABCD	T4
Hazard Type	Area Classification	Gas or Dust Group	Temperature Code

North American Temperature Codes

TEMPER-ATURE CODE	MAXIMUM SURFACE TEMPERATURE	
	°C	°F
T1	450	842
T2	300	572
T2A	280	536
T2B	260	500
T2C	230	446
T2D	215	419
T3	200	392
T3A	180	356
T3B	165	329
T3C	160	320
T4	135	275
T4A	120	248
T5	100	212
T6	85	185

XII. BASIC ELECTRICAL FORMULAE:



Note: "V" comes from "voltage" and **"E"** from "electromotive force". **"E"** means also energy.

- **Common Electrical Formulae:**

Voltage - V = I × R = P / I = √(P × R) - in volts V
Current - I = V / R = P / V = √(P / R) - in amperes A
Resistance - R = V / I = V2 / P = P / I2 - in ohms Ω
Power - P = V × I = R × I2 = V2 / R - in watts W

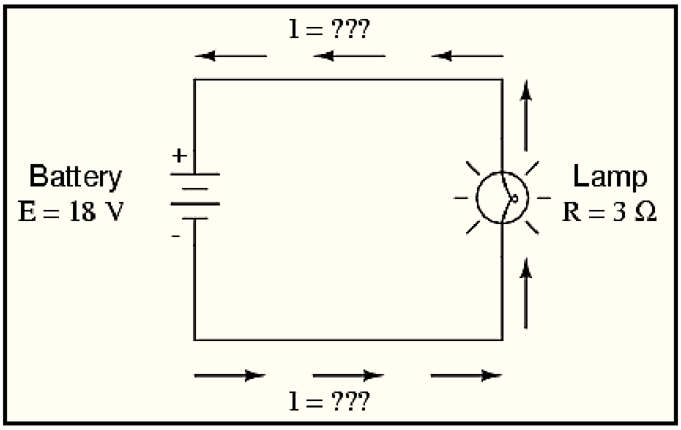
- **Table of Common Electrical Formulae:**

AC/DC Formulas				
To Find:	**Direct Current**	**AC / 1phase 115v or 120v**	**AC / 1phase 208,230, or 240v**	**AC 3 phase All Voltages**
Amps when Horsepower is known	HP x 746 E x Eff	HP x 746 E x Eff X PF	HP x 746 E x Eff x PF	HP x 746 1.73 x E x Eff x PF
Amps when Kilowatts is known	kW x 1000 E	kW x 1000 E x PF	kW x 1000 E x PF	kW x 1000 1.73 x E x PF
Amps when kVA is known		kVA x 1000 E	kVA x 1000 E	kVA x 1000 1.73 x E
Kilowatts	I x E 1000	I x E x PF 1000	I x E x PF 1000	I x E x 1.73 PF 1000
Kilovolt-Amps		I x E 1000	I x E 1000	I x E x 1.73 1000
Horsepower (output)	I x E x Eff 746	I x E x Eff x PF 746	I x E x Eff x PF 746	I x E x Eff x 1.73 x PF 746

Obs.: E = Voltage / I = Amps /W = Watts / PF = Power Factor / Eff = Efficiency / HP = Horsepower

Example:

In this circuit below, we have a battery voltage of 18 V and a lamp resistance of 3 Ω. Using above concepts, determine current and power:



Then,

$$\boxed{I = \frac{E}{R} = \frac{18\ \text{V}}{3\ \Omega} = 6\ \text{A}}$$

To determine power,

$$\boxed{P = I\,E = (6\ \text{A})(18\ \text{V}) = 108\ \text{W}}$$

XIII. BOLT TORQUE EVALUATION:

In pipelines, choosing a gasket that is compatible with the fluid and compatible with the operating pressure and temperature such as a 1/8" thick rubber gasket, the ASME VIII Div.1 - Appendix 2, tells us that the gasket is **group Ia** and our choice is compatible with the recommendation of ASME B16.5. The ASME VIII Div.1 - Appendix 2, give us two gasket factors:

m = gasket factor = 2.00;
y = minimum design seating pressure = 1,600 psi.

The "m" factor is an experimentally determined factor. It is the ratio of the compressive pressure to be exerted on the gasket during assembly, to the highest system pressure in service. For example a catalog may specify:

y = 1600 psi for a 3/16" gasket,
y = 2100 psi for 1/4";
y = 2600 psi for 3/8";
y = 3000 psi for 1/2";

Example:

Using a carbon steel water piping with 4", with a design pressure of **165 psi** and a design temperature of 70°F", flange class 150 #, ASME B16.5. Knowing the flange will require **8 bolts of 5/8" diameter**, calculate the bolting stress. Use minimum required bolt preload, **Wm = 9,000 lb**.

Consider the load needed to stress the gasket to a value "y" and seat the gasket. In our case **y = 1600 psi**. We need a **class 150 flange, 8-bolts assembly**, to sustain a preload **Wm = 9000 lb.**. At this installation, each bolt must have a tension of at least:

Bolt tension: F = 9,000/8 = **1125 lb.**

According to the tabel below (and Table 8 of ASME B16.5), for a 4" class 150 lb flange. Using the external diameter of the 5/8" bolt is we find an area of 0.5168", which corresponds to:

Bolt root area: 5/8 – 11 threads/inch = **0.202 in².**

Size	Major Dia	Threads Per Inch	Pitch Dia	Minor Dia External	Minor Dia Internal	Minor Dia Area
3/8	0.375	16	0.3344	0.3005	0.3073	0.0678
½	0.5	13	0.45	0.4084	0.4167	0.1257
5/8	**0.625**	**11**	**0.566**	**0.5168**	**0.5266**	**0.202**
¾	0.75	10	0.685	0.6309	0.6417	0.302
1	1	8	0.9188	0.8512	0.8647	0.551

Given the installation tension of **1,125 lb per bolt**, over an **area of 0.202 in²**, the tensile stress applied to the bolt during preload to compress the joint is:

Bolt tensile stress: σ = F/A bolt = 1,125/0.202 = **5,569 psi.**

The **ASTM A193 Gr.B7** bolt at ambient temperature, its allowable stress is S = 23,000 psi. The bolt yield and ultimate strength is Sy = 95,000 psi. Using the **minor root diameter of bolt 5/8**", the **preload stress of 5569** psi is well within the material allowable stress. **Other calculation** to minimum bolt torque **Tmin**., needed to achieve a preload is:

Tmin = K.Fi.d, where:

Tmin = minimum bolt torque, in-lb.;
K = nut factor (lubricated bolts = 0.10 ~ 0.20); hot dip galvanized bolts = 0.25); (plain bolts = 0.20);
Fi = (1125 lb recommended preload), lb.;
d = nominal bolt diameter, in.

Using the **table below**: **Clampload** is calculated at **75% of the proofload** and is only a estimated number, to be tensioned to a different value.

T = K.D.P, where:

T = Torque,
K = torque coefficient (see table),
D = nominal diameter (inches),
P = bolt clamp load, lb (see table)

Torque-Tension Relationship for ASTM A193 B7 Bolts and Studs

Nominal Dia. (in.)	Threads Per Inch	Minimum Tensile Strength (lbs.)	Minimum Yield Strength (lbs.)	Est. Shear Strength (lbs.)	Clamp Load (lbs)	Tightening Torque K = 0.12 (ft-lbs)	Tightening Torque K = 0.15 (ft-lbs)	Tightening Torque K = 0.20 (ft-lbs)
1/4	20	3978	3341	2016	2506	6	8	10
1/4	28	4547	3819	2441	2864	7	9	12
5/16	18	6554	5505	3401	4129	13	16	22
5/16	24	7258	6097	3931	4573	14	18	24
3/8	16	9686	8136	5083	6102	23	29	38
3/8	24	10979	9222	6063	6916	26	32	43
7/16	14	13289	11162	6997	8372	37	46	61
7/16	20	14840	12465	8173	9349	41	51	68
1/2	13	17737	14899	9425	11175	56	70	93
1/2	20	19994	16795	11146	12596	63	79	105
9/16	12	22743	19104	12150	14328	81	101	134
9/16	18	25373	21313	14159	15985	90	112	150
5/8	11	28250	23730	15131	17798	111	139	185
5/8	18	31995	26876	17999	20157	126	157	210
3/4	10	41808	35118	22643	26339	198	247	329
3/4	16	46620	39161	26344	29371	220	275	367
7/8	9	57717	48482	31438	36362	318	398	530
7/8	14	63684	53495	36035	40121	351	439	585
1	8	75718	63603	41316	47702	477	596	795
1	14	84986	71388	48473	53541	535	669	892
1 1/8	7	95409	80144	51969	60108	676	845	1127
1 1/8	8	98807	82998	54570	62248	700	875	1167
1 1/4	7	121139	101757	66722	76318	954	1192	1590
1 1/4	8	124963	104969	69664	78727	984	1230	1640
1 1/2	8	186480	156644	105376	117483	1762	2203	2937
1 1/2	6	175657	147551	97013	110664	1660	2075	2767
1 5/8	8	221841	186346	125992	139760	2271	2839	3785
1 3/4	8	260269	218626	148450	163970	2869	3587	4782
1 7/8	8	301766	253483	172748	190112	3565	4456	5941
2	8	346330	290917	198887	218188	4364	5455	7273
2 1/4	8	444663	373517	256688	280138	6303	7879	10505
2 1/2	8	555267	466425	321851	349819	8745	10932	14576

- **Calculation using the bolt stress area, according to ASTM 574:**

$$A = 0.7854\left(D - \frac{0.9743}{n}\right)^2$$

Using this formula a 5/8" – 11 threads/inch, the stress area is = **0.226 in^2**

Where:

D = Nominal diameter, in.;
n = Number of threads per inch;

- **Common Bolt Materials – Torque:**

ASTM A307:

Bolt Size	Tightening Torque (ft-lb)		
	Waxed	Galv	Plain
1⁄4	2	4	4
5⁄16	4	9	7
3⁄8	7	16	13
7⁄16	10	26	21
1⁄2	16	40	32
9⁄16	23	58	46
5⁄8	32	79	64
3⁄4	56	141	113
7⁄8	83	208	166
1	125	313	250
1 1⁄8	177	443	354
1 1⁄4	250	625	500
1 3⁄8	327	819	655
1 1⁄2	435	1088	870
1 3⁄4	748	1870	1496
2	1125	2813	2250
2 1⁄4	1645	4113	3291
2 1⁄2	2250	5625	4500
2 3⁄4	3050	7626	6101
3	4030	10074	8060
3 1⁄4	5192	12980	10384
3 1⁄2	6560	16400	13120
3 3⁄4	8151	20377	16301
4	9972	24930	19944

SAE GRADE 2:

Bolt Size	Tightening Torque (ft-lb)		
	Waxed	Galv	Plain
1⁄4	3	7	5
5⁄16	6	14	11
3⁄8	10	25	20
7⁄16	16	40	32
1⁄2	24	61	49
9⁄16	35	88	70
5⁄8	48	121	97
3⁄4	86	216	173
7⁄8	83	208	166
1	125	313	250
1 1⁄8	177	443	354
1 1⁄4	250	625	500
1 3⁄8	327	819	655
1 1⁄2	435	1088	870

ASTM A325:

Bolt Size	Tightening Torque Range (ft-lb) (Min - Max)	
	Waxed	Plain
1⁄2	50 - 58	100 - 117
5⁄8	99 - 120	198 - 240
3⁄4	175 - 213	350 - 425
7⁄8	284 - 343	569 - 685
1	425 - 508	850 - 1017
1 1⁄8	525 - 625	1050 - 1256
1 1⁄4	740 - 885	1479 - 1771
1 3⁄8	974 - 1169	1948 - 2338
1 1⁄2	1288 - 1550	2575 - 3100

XIV. COMMISSIONING PROCESSES:

Commissioning is a **systematic process** of ensuring that all **equipment systems perform** interactively according to the contract documents, the design intent and the owner's operational needs. This is achieved ideally by **beginning in the pre-design phase** with design intent development and documentation, and continuing through design, construction and the warranty period with actual verification through review, testing and documentation of performance.

The commissioning process integrates the traditionally separate functions of **design peer review**, equipment startup, control system calibration, testing, adjusting and balancing, equipment documentation and facility staff training, and adds the activities of documented functional testing and verification.

Commissioning is occasionally **confused with testing**, **adjusting and balancing (TAB)**. Testing, adjusting and balancing **measures building air and fluid flows**, but commissioning encompasses a much broader scope of work. Building commissioning typically involves four distinct "phases" in which specific tasks are performed by the various team members throughout the construction process.

The **four phases** are pre-design, design, construction, and warranty. As part of the construction phase, commissioning involves functional testing to determine how well mechanical and electrical systems meet the operational goals established during the design process. Although commissioning can begin during the construction phase, owners receive the most cost-effective benefits when the process begins during the pre-design phase at the time the project team is assembled.

A properly commissioned facility can result in **fewer change orders** during the construction process, fewer call-backs, long-term tenant satisfaction, lower energy bills, avoided equipment **replacement costs**, and an **improved profit margin** for building owners once the building is occupied. Commissioning also assures that the building's operational staff is properly trained and that the operations and maintenance manuals are compiled correctly at project turn-over.

- ### Benefits of Commissioning:

Until recently, the most frequently mentioned benefit of commissioning was **its energy related** value. Building commissioning ensures that the **energy savings** expected from the design intent are implemented correctly. While these benefits are significant, they are far outweighed by the non-energy-related benefits of commissioning. These include:

• Proper and efficient equipment operation
• Improved coordination between design, construction and occupancy
• Improved indoor air quality, occupant comfort, and productivity
• Decreased potential for liability related to indoor air quality, or other HVAC problems
• Reduced operation and maintenance costs

- ### Existing Building Commissioning:

Commissioning also can be **applied to existing buildings** to restore them to optimal performance. Retrocommissioning is a systematic, documented process that identifies low-cost O&M (Operation & Maintenance) improvements in an existing building and brings it up to the design intentions of its current usage. In many cases as a building is used over time, equipment efficiency and tenant build-outs or renovations change how the building functions.

Retrocommissioning identifies and solves comfort and operational problems, explores the full potential of the facilities energy management system, and ensures that the equipment performs properly after space changes have been made. Continuous commissioning is similar to retrocommissioning and begins by identifying and fixing HVAC and comfort problems in the building.

In continuous commissioning, when the commissioning is complete, the team continues to work together to monitor and analyze building performance data provided by permanently installed metering equipment. This process works to ensure that the savings achieved from the commissioning continue to persist over time.

- **The Commissioning Team:**

The **commissioning team does not manage the design and construction** of the project, but may include facility staff for possibly testing or diagnostic the utility process equipment. Its purpose is to promote communication among team members and the early identification and resolution of problems.

Any project involving commissioning should begin with a **commissioning scoping meeting**, which all team members are required to attend. At this meeting, the roles of each team member are outlined and the commissioning process and schedule are described. Commissioning team members most often include the building owner or project manager, commissioning provider, design professionals, installing contractors and manufacturer's representatives.

- **Professional Qualifications:**

• Direct responsibility for project management of at least two commercial construction or installation projects with mechanical costs greater than or equal to current project costs;
• Experience in design installation and/or troubleshooting of direct digital controls and energy management systems, if applicable.
• Demonstrated familiarity with metering and monitoring procedures.
• Knowledge and familiarity with air/water testing and balancing.
• Experience in planning and delivering O&M training.
• Building contracting background and complete understanding of all the building systems, including building envelope, structural, and fire/life safety components.

- **Testing Specialists:**

If the complexity of the project **requires special testing**, the specialists performing these tests should also be involved in commissioning. Test results and recommendations from these specialists should be submitted to the commissioning provider for review. They may also be required to review documentation relating to the systems they test and to train operators on the proper use of this equipment.

- **Design Phase:**

The optimum time to hold the commissioning scoping meeting is during the design phase. At this meeting, the commissioning provider outlines the roles and responsibilities of the project team members with respect to commissioning and reviews the commissioning plan outline and schedule. Team members provide comment on the plan and schedule, and the commissioning provider uses these suggestions to complete the final commissioning plan.

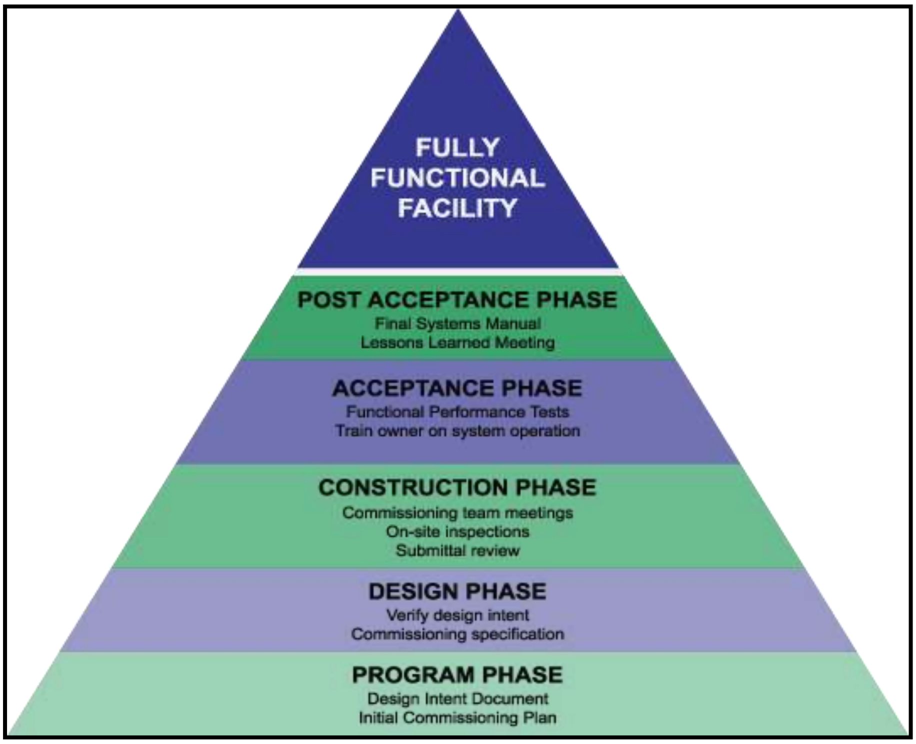
The main commissioning tasks during this phase are compiling and reviewing design intent documents (owner's project requirements and their related acceptance criteria), if not already developed, incorporating commissioning into bid specifications, and reviewing bid documents.

During the beginning of design the designer develops their design concepts which they propose to use to meet the owners project requirements. They also document the assumptions (design basis) used in their design for sizing and selection of systems (i.e. codes followed, temperature parameters, occupancy loads etc.) The **design concepts and design basis** are compiled into a design narrative document which the commissioning provider reviews for clarity, completeness and compliance with the design intent. As the design progresses, the design narrative is compared to the design intent.

- **Construction Phase:**

During the construction phase, the verification checklists, sometimes referred to as "prefunctional tests" are used to ensure that **equipment is properly installed** and ready for functional testing. These checklists are usually completed by the suppliers. The commissioning team oversees the assembly, the construction checklists, accessories evaluation and makes sure that any deficiencies are remedied before the functional testing begins.

During this phase, the **commissioning team reviews** contractor submittals of commissioned equipment, operation and maintenance manuals, may write test plans for each process or system, supervise the equipment accessories to be commissioned and also visits the construction site periodically to observe conditions that might affect system performance or operation.



- **Minimum Expected Deliverables:**

1. Commissioning plan and schedule detailing each step of the commissioning process and each team member's role and responsibilities accomplishing a diagnostic and functional test plan detailing how each test will be accomplished and noting expected performance parameters.

2. A list of findings and potential improvements identified by the commissioning provider for design phase and construction phase activities such as a training plan recommending specific topics and training schedules. At the completion of the project, a final commissioning report detailing all of the commissioning provider's findings and recommendations including copies of all functional performance testing data.

3. A systems concepts and operations manual gives a description of each system with specific information about how to optimally operate and control the system during all modes of operation such as during fire, power outage, shutdown, etc., including special instructions for energy efficient operation and recommissioning.

4. Energy savings and implementation cost estimates for recommendations developed in the process are also deliverables in retrocommissioning projects.

After **completing** functional testing, the **provider writes a final commissioning report** and submits it to the owner for review. In addition to the final report some commissioning projects include a more comprehensive documentation package to assist the owner in understanding, operating and maintaining their systems.

- **Warranty Phase:**

The commissioning team must be careful when considering any equipment warranties. The client should require that all suppliers provide the commissioning link with a full set of warranty conditions for each piece of equipment to be commissioned. Some warranty provisions may require that the installing contractors perform every testing, under the supervision of the commissioning team.

Any testing that was delayed because of site or equipment conditions or inclement weather, should be completed during the warranty. Although some testing of heating and cooling systems may be performed under simulated conditions during the off-season, natural conditions usually provide more reliable results.

- **Commissioning Finalization:**

Certainly no one could reasonably expect the operation staff learn to perform equipment and systems in a short time. Then, the operation and management staff should be encouraged **to recommission** selected systems on a regular basis, perhaps **every 2 or 3 years** depending on building usage, equipment complexity, and operating experience. In the meantime, implementing regular, sound operation and maintenance practices ensures that the savings from commissioning can last.

- **Training:**

Operation and maintenance manuals are useful reference tools for current facilities staff and can also be used as a training resource for all staff members. All suppliers should be required to provide at least **three copies of each manual** to the client. Typically, **the master copy** remains in the facility manager or engineers office. The **second copy** functions as a field copy, and selected pages from it may be removed for use during site work. The **third copy** stays with the client, his legal representative or management firm's office.

Some companies have found it beneficial to "hard bind" the master copy, so that pages cannot be removed and misplaced. If building equipment will be maintained and operated by an outside firm, a fourth copy should be requested and provided to them as a reference. The management and operational staff must remember that manuals lose their usefulness if they are not kept up to date, any pages added to them, such as checklists or preventive maintenance work orders, must be included in each copy. The common suggested traing topics are:

Equipment start-up and shutdown procedures, operation in normal and emergency, modes, seasonal changeover, manual/automatic controls;

• Recommendations for special tools and spare parts inventory and emergency procedures;
• Requirements and schedules for maintenance operation and maintenance-sensitive equipment;
• Health, safety issues, fire combat and building walk-through procedures;
• Operation and adjustment of dampers, valves and controls;
• Hands-on operation of equipment and systems, common troubleshooting problems, their causes and corrective actions;
• Review of operation, maintenance manuals and their location on-site;
• Review of related design intent documents.
• Energy management practices, control system operations and noise control;
• Relevant commissioning reports and documents, when and how to recommission equipment and systems.
• Predictive and corrective maintenance work order management system.

By **videotaping** each **training session**, including the hands-on start-up and shut-down procedures for equipment, building operation staff gains a permanent, inexpensive onsite training aid and when a new staff are hired, the videos can be viewed as part of their trainings. For buildings where a facility manager without a technical background provides maintenance, the commissioning manager can still coordinate with suppliers to ensure that **the manager is educated** about the capabilities, intended function, and required maintenance of the building systems. It is important to provide a **list of all resources** for the manager to call for maintenance assistance when necessary.

- **Energy Accounting:**

Energy accounting is a method of tracking a facilities energy use over time. Many facility managers seeking peak performance in their building have found that energy accounting software gives them a better understanding of their utility expenditures. Each month's usage and expenditures are input into a software program. The software then tracks the usage while normalizing for temperature changes over the period being analyzed.

The energy "accountant" can then watch and see whether the facility performs as expected or uses more energy than expected over time. If higher than expected usage occurs, further investigation can identify the occupancy and or usage changes, equipment problems, or other unknown problems that have increased the energy bills.

- **Preventive Maintenance Plan:**

Consists of a checklist of tasks that are performed at manufacturer-recommended intervals (usually measured in hours of equipment run time). This checklist is usually kept in the form of a log and updated manually when tasks are performed. In buildings that use computerized maintenance management systems, the equipment that requires preventive maintenance should be entered into the system.

If the **computerized system** is used for generating preventive maintenance work orders, **update the system** and keep hard copies of completed work orders in a file or notebook. Another low cost measure to consider is **programming the energy management system** to track and archive equipment run times. This is most easily, and least expensively, done when the initial system programming takes place, and should be specified in the original equipment specification in the contract.

When estimating service life, the manufacturers usually assume regular preventive maintenance of the equipment and system components. Many **preventive maintenance** procedures recommended by manufacturers are intended to extend the life of the component and the system as a whole. Lack of preventive maintenance reduces the equipment life. Performing regular preventive maintenance can result in energy and cost savings.

For example, simply replacing worn fan belts on a regular basis can **save 2-4%** of the energy used to run the fans. Cleaning air filters and cooling coils regularly can **save 1-3%** of the building's energy use for cooling. These basic activities cost very little to perform, but can add up to dramatic savings.

Identifying **degradation** of the system's components is another benefit of preventive maintenance. A proper facility operation and maintenance system that includes reporting and documentation reduces the incidence of failure. For example, if a component of the system is identified as **potentially failing** to operate as intended, a work order for replacement parts can be set up immediately and work scheduled during unoccupied hours. Preventive maintenance can reduce the number and cost of emergency corrective maintenance bills.

Preventive maintenance should be performed according to manufacturer requirements. Consult the manufacturer's operation and maintenance manual for each piece of equipment for requirements such as frequency, chemical treatments, proper lubricants, special tools, etc. This information should also become a part of the preventive maintenance plan.

- **Commissioning of Green Constructions:**

Many building owners are increasingly concerned with issues of resource efficiency, environmental impact, and occupant health and productivity. They are beginning to request that their facilities be designed and constructed with **"green" features that minimize environmental impact** and maximize occupant productivity. Certain federal, state and local government agencies, as well as a number of private owners, now require their facilities to meet a **"green" standard**.

Green buildings often employ systems that use **renewable resources** such as solar energy or wind power and low-energy HVAC systems with natural ventilation or evaporative cooling. They may also employ systems that conserve water through rainwater and gray water recovery. All of these technologies can make a significant contribution to the **sustainability of a project**, but they add complexity to building design and construction, as well as commissioning, since the technologies are less thoroughly understood.

The commissioning of green constructions includes ensuring that:

• The design **meets the desired green building certification criteria** and the design decisions and rationale behind them are adequately documented;

• Green **materials are adequately specified** and installed, specifications and drawings are clear and complete.

• The **green products or features** will not have a negative impact on other building systems and the appropriate O&M documentation and staff training can properly maintain the green features.

The United States Green Building Council (USGBC) developed the **LEED** (Leadership in Energy and Environmental Design), a **green building rating and certification system** to provide guidance to designers. The **LEED buildings earn points** such as bronze, silver, gold or platinum ratings, in six general categories:

- ✓ Sustainable Sites,
- ✓ Water Efficiency,
- ✓ Energy & Atmosphere,
- ✓ Materials & Resources,
- ✓ Indoor Environmental Quality,
- ✓ Innovation & Design.

Although these steps are part of any good commissioning process, the need to document these steps for LEED purposes and coordinate with other members may add costs to the commissioning work. In addition, LEED requires that the **functional testing of the heating and cooling systems** occur during the heating and cooling seasons respectively. While this is desirable, it is not mandatory for a non-LEED commissioning process, and thus, it may incur additional commissioning costs.

- **Typical Commissioning Activities:**

Mechanical:

• Visual inspection for complete and correct installation.
• Internal inspection of tanks and vessels.
• Alignment.
• Load testing of lifting equipment.
• Hot oil flushing.
• Bolt tensioning.
• Dimension control.
• Preservation,
• Hydraulic and/or pneumatic testings.

Electrical:

• Visual inspection for complete and correct installation.
• Insulation and continuity testing of cables.
• Insulation testing of generator, transformers and motors, panels, distribution board etc.
• Earthing checks.
• Static check of switches and control devices.
• Battery preparations.
• Lighting and socket outlet checks.
• Area completion.
• Heat tracing.
• Preservation.

Instrument/Telecommunication:

• Calibration and testing of instruments prior to installation.
• Visual inspection for complete and correct installation.
• Insulation and continuity testing of cables.
• Cleaning, flushing, pressure and leak testing of pneumatic and hydraulic tubing.
• Adjustment of control, alarm and shutdown settings.
• Loop testing.
• Function testing of control systems.
• Function testing of field instruments.
• Hot oil flushing of instrument tubing.
• Area completion.
• Preservation.

Piping:

• Welding inspection.
• Chemical cleaning and testing of pipework.
• Drying of tested pipework.
• Preservation of tested pipework.
• Reinstatement of all items after testing.
• Final inspection of pipework.
• Test ISO's and P&ID's showing the extent of each pressure test.
• Hydraulic and/or pneumatic testing
• Removal of items subject to damage during flushing, cleaning and pressure testing
• Flushing of pipework.
• Hot oil flushing of pipework.
• Bolt tensioning.
• Pipe supports completed.
• Insulation.
• Flow coding.

HVAC:

• Visual inspection for complete and correct installation.
• Cleaning of ductwork.
• Leak testing of ductwork.

• Alignment checks.
• Mechanical function checks of equipment.
• Preservation.
• Flow coding.

Structural:

• Visual inspection for complete and correct installation.
• QC documentation.
• Welding.
• Load testing of lifting lugs and monorails.

Surface Protection, Insulation and Fire Proofing:

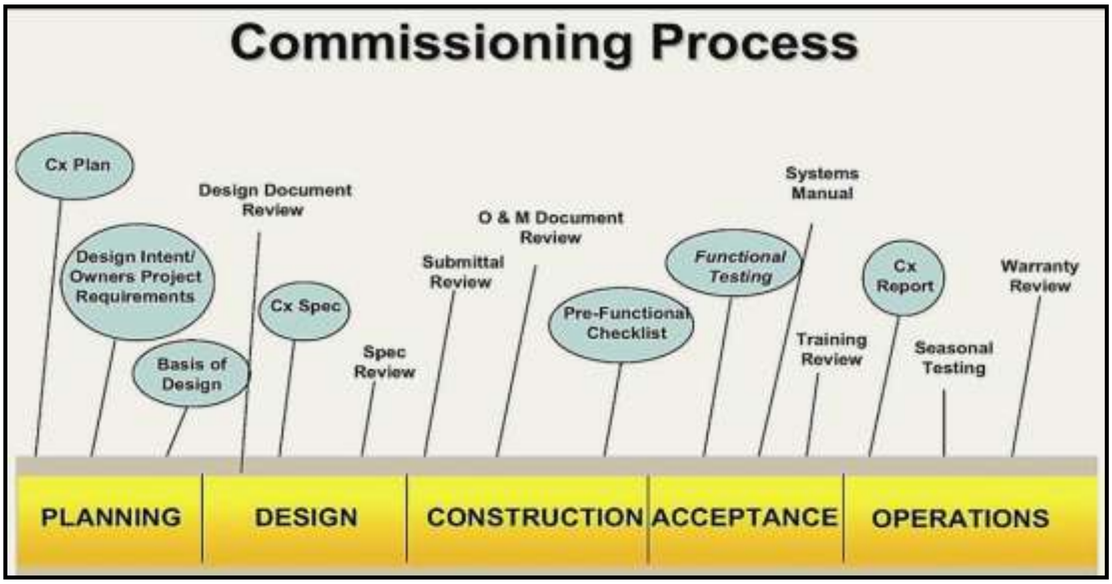
• Visual inspection for complete and correct application/installation.
• Thickness verification.
• Adhesion checking.
• Preservation.
• Insulation.
• Painting.
• Fire proofing.

Architectural:

• Visual inspection of civil installation
• Arrangement of facilities
• Preservation.

Safety:

• Visual inspection for complete safety installation
• Fire combat equipment
• Area walk-through



Practical Example:

This appendix includes an example for the documentation needed to **commission an Air Handling System.** There are two conditions: the clients's Project Requirements and the Acceptance Criteria documented by the Commissioning Team to what is commonly referred to as "design intent." This example illustrate the relationship between the various components of design intent, which are:

• Clients's Project Requirements
• Design Intent Acceptance Criteria
• Design Basis

- **Parameters and requirements for an Air Handling System:**

HVAC Items:	Office Area Functions:
Temperature requirements and limitations	1. Temperature parameter: 72°F - 75°F. 2. Verify space sensor accuracy. 3. Verify terminal unit performance by testing and balancing work and spot checks, ±10% of design flow rate required.
Humidity requirements and limitations	1. Humidity parameter: 30% - 60% RH 2. Verify accuracy of all central system sensors for ±0.5°F for temperature and ±5%RH for humidity.
Pressure relationship requirements and limitations	1. Verify the relief dampers are controlled to provide a stable building pressure; 2. Verify the CO^2 sensors per the controlled ventilation portion of the operation sequence; 3. Verify the pressurization at minimum outdoor air flow during peak cooling season; 4. Check building air flow balance (supply, return, minimum outdoor air and exhaust) to be verified by testing and balancing contractor via traverse of the supply, return and exhaust;
Filtration requirements and limitations	1. Verify filter installation per the specification requirements; 2. Verify clean filter pressure drop meets the manufacturers specifications; 3. Verify photohelic gauges are installed and properly set; 4. Verify that the intake compartment remains relatively free of moisture and that any moisture that does enter the compartment.
Air change requirements and limitations	1. Review the balancing report to verify system performance; 2. Spot check by testing and balancing measurements according to commissioning specifications.
Sound and noise level requirements	Ckeck the office square footage for sound power levels; include locations directly adjacent to the area rooms;
Hazardous or noxious effluents discharged to the air flow.	Verify positive exhaust at locations per the requirements of the construction documents via the testing and balancing process;
Integrated performance requirements with other air handling systems	Spot check system performance via trending and site visits according to requirements of the commissioning specifications.
Normal operating occupancy schedule	Check if the acceptance criteria is as indicated in the commissioning specifications, equipment failures and shut-downs.

- **Evaluation by the Commissioning Team:**

HVAC Items:	Acceptance Criteria:
Temperature requirements and limitations	1. Space sensor accuracy verified by factory calibration certificates and checked via commissioning process; 72 ±1.5°F – 75 ±1.5°F, as required. 2. The unit performance was verified by testing and balancing and spot checked by the commissioning process and found ±10% of design flow rate as required with stable operation, reheated only after volume reduction to minimum air flow is necessary.
Humidity requirements and limitations	1. Summertime humidity levels controlled by the cooling coil discharge temperature. No verification of wintertime humidity was required. Verified the accuracy of all central system sensors for ±0.5°F for temperature and ±5% RH for humidity. 2. Spot checked the space humidity levels and also verified during peak cooling season: 50% RH ±5%.
Pressure relationship requirements and limitations	1. Verified the relief dampers are controlled to provide a stable building pressure of .01-.05 inches w.c. during the economizer cycle per the operating sequence. Spot check at critical points (peak heating, peak cooling, swing seasons and first month of operation. 2. Verification of the set point reset via the CO^2 sensors per the controlled ventilation portion of the operation sequence. Sensor accuracy verified by factory calibration certificates; ±50 ppm, as required. 3. Verified pressurization at minimum outdoor air flow during peak cooling season; .01-.05 inches w.c. positive relative to the outdoors, measured at the entry vestibule, as required. 4. Verified the building air flow balance (supply, return, minimum outdoor air and exhaust): ±10% of the supply flow are equal to the return flow plus the minimum outdoor air flow. The exhaust flow is equal to the minimum outdoor air flow minus 1,000 cfm for the building pressurization.
Filtration requirements and limitations	1. The filter installation is per the specification requirements, 65% ASHRAE dust spot efficiency, as required. 2. Filter pressure drop meets the manufacturers specifications ±2%.; 3. The photohelic gauges are installed and properly set at the required pressure. The indicators should be cleaned according to requirements. Clean filter pressure drop 0.9 in. w.c., dirty filter pressure drop 19 in. w.c; 4. Inspected on a peak cooling day the cooling coil and the drain pan with the fan operating at full flow. The intake compartment remains relatively free of moisture, as required.
Air change requirements and limitations	The air change was checked by balancing sensors, as per the requirements of the commissioning specifications.
Sound and noise level requirements	Sound and noise levels were spot checked about 10% of the office square footage; maximum allowable dB = 65, as required.
Hazardous or noxious effluents discharged to the air flow.	1. Verified Hazardous to the air flow and the locations via balancing process; noxious effluents discharged design flow ±10%, as required.
Integrated performance requirements with other air handling systems	The assembled systems are according to requirements of the acceptance criteria as indicated in the commissioning specifications. Spot check ongoing system performance via trending and site visits.
Normal operating occupancy schedule	The system was verified according to design specifications, to normal occupancy, and is able to recover safely from power outages, equipment failures and scheduled shut-downs to 25% allowance, as required.

Example – Commissioning Record:

<Project> MCCR-R-02	Commissioning Record CENTRIFUGAL, SCREWPUMP, COMPRESSOR OR HYDR. MOTOR	Sheet No.	

Tag No. :		MC Package No.
Description :	Area :	
PO No. :	System :	Comm.Package No.
Manufacturer :	Subsystem :	

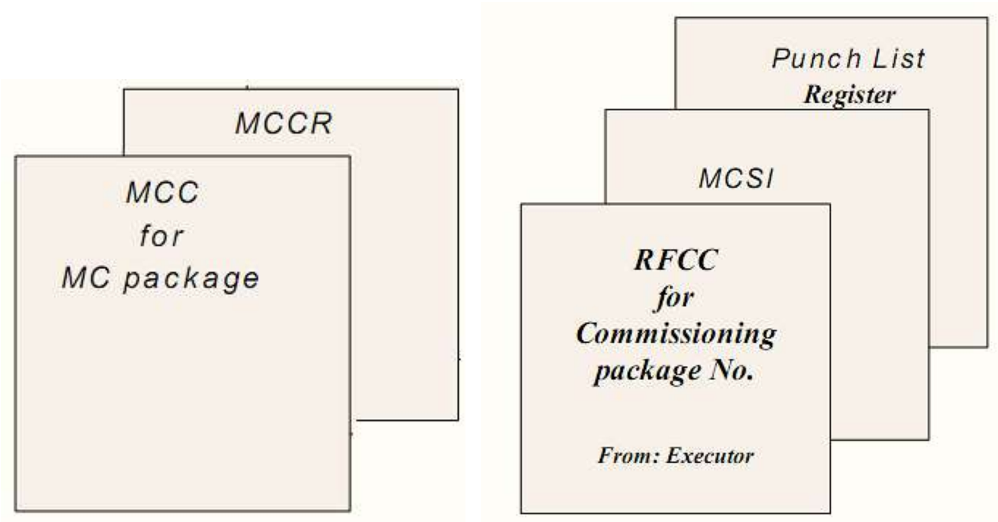
	INSPECTION ITEM	SUPPL.	FABR.	HOOK-UP	Punchlist item No.
01	Dataplate complies with data sheet				
02	Check CE-marking				
03	Skid installation correct				
04	Dowels fitted in pump feet				
05	Alignment Jack screws fit for driver				
06	Correct shimspack for driver fitted				
07	Alignment checked, see procedure				
08	Jack screws retracted after alignment				
09	Transmission checked				
10	Coupling guard checked				
11	Lubricant or preservation oil filled				
12	Constant oiler removed				
13	Grease nipples fitted				
14	Gland packing fitted				
15	Gland cooling fitted				
16	Mechanical seal fitted				
17	Pumpcase drain valve installed				
18	Pumpcase vent valve installed				
19	Drain line from skid pan installed				
20	Inlet/Outlet checked				
21	Skid mounted valves checked				
22	Paintwork completed				
23	NDE carried out				
24	Material certificate checked				
25	Pressure test carried out				

COMMENTS:

VERIFIED		SUPPLIER		FABRICATION		HOOK-UP
Name Sign Date	Executor		Executor		Executor	
Name Sign Date	Comp.		Comp.		Comp.	

Note: "Hook up" refers to making the connections from the utilities needed for the function controls. The **"commissioning"** refers to activating the system once it is "hooked up". You check out the connections with testing, verifying accurately if the controls are working, as required. The most effective commissioning method to complete the "hook-up" of a facility is **by area**.

- **Documentation for a Commissioning Package:**



MCCR (Mechanical Completion Check Record):
• Discipline checklist for the various equipment.
• MCCRs shall end up in status OK - PA – PB

MCC (Mechanical Completion Certificate):
• States that all discipline related inspections and tests for a MC package have been carried out according to relevant contract documents.
• MCC shall end up in status OK – PB

Punch List Register:
• Form on which the executor records any outstanding work.

MCSI (Mechanical Completion Status Index):
• A computerised listing with status for the completed package

RFCC (Ready for Commissioning Certificate):
• Formal document for transfer a Commissioning package from MC Executor to Commissioning.

References:

http://www.ndt-ed.org;
http://www.inspection-for-industry.com;
ASME Section I & Section VIII;
ASME B31.1 - Power Piping;
ASME-B31.3 - Process Piping;
ISA-75.01.01, Flow Equations for Sizing Control Valves;
API 598, Valve Test Procedures;
API 610 – Pump Testing
MSS SP-61 - Pressure Testing of Steel Valves
American Petroleum Institute;
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